Exploring the Possibilities of Mariculture for Promoting Blue Economy of the St. Martin's Island, Bangladesh

A dissertation submitted to the Department of Disaster Science and Climate Resilience, University of Dhaka as partial fulfillment of the degree of Doctor of Philosophy (PhD)

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Declaration

I do hereby declare that the thesis work with the title "Exploring the Possibilities of Mariculture for Promoting Blue Economy of the St. Martin's Island, Bangladesh" is an original research work carried by me under the supervision of Dr. A. S. M. Maksud Kamal (Supervisor), Professor, Department of Disaster Science & Climate Resilience and Dr. Md. Kawser Ahmed (Co-supervisor), Professor; Department of Oceanography, University of Dhaka, Bangladesh. The dissertation submitted to the Department of Disaster Science and Climate Resilience, University of Dhaka as partial fulfillment of the degree of Doctor of Philosophy (PhD). The thesis contains no materials previously published to the best of my knowledge and belief, except where proper references are included in this thesis itself. I would want to assert that I will assume full responsibility for any future instances of similarity, even if they arise from an unpublished paper. It should be noted that my supervisor and co-supervisor will not bear any responsibility in such cases.

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Dedicated

to

My Parents and Spouse

Approval Certificate

This is to certify that Md. Jobaer Alam bearing Registration No: 118/2018-2019, Session: 2018-2019, is a PhD student of the Department of Disaster Science & Climate Resilience, Faculty of Earth and Environmental Sciences, University of Dhaka, Dhaka-1000, Bangladesh. His research work is entitled as **"**Exploring the Possibilities of Mariculture for Promoting Blue Economy of the St. Martin's Island, Bangladesh**".**

It is also stated that the work given here is entirely original research and eligible for submission in terms of style and substance to the University of Dhaka as partial fulfillment of the degree of Doctor of Philosophy (PhD) in the Department of Disaster Science & Climate Resilience.

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-The Author

Abstract

Bangladesh, a nation situated on the northern coast of the Bay of Bengal, has been endowed with a wide range of natural resources. The ocean has a crucial role in driving socio-economic advancement through stimulating economic activities throughout the country, particularly in coastal regions. The notion of the ocean's economy, commonly known as the blue economy, is a multifaceted approach that aims to foster economic expansion, ensure environmental sustainability, promote social inclusivity, and enhance the resilience of marine ecosystems. St. Martin's Island, the sole island that bears coral in Bangladesh, is unquestionably among the most cherished possessions and has been chosen as the study area due to its unique geography, size and location within the coastal zone. Furthermore, this region serves as an appropriate pilot model location due to its abundance of readily accessible data resources.

This study emphasizes the potential of mariculture in promoting the growth of the blue economy on the island. The objectives of the study were to determine the best site, season, and species of fish and seaweed to be cultivated in the coastal waters adjacent to the Island. In order to accomplish the study's goal, the present research work examined the composition, abundance, and distribution of physiochemical properties, plankton, nutrients and heavy metals in the coastal waters of the Bay of Bengal in the vicinity of St. Martin's Island, Bangladesh. Twelve distinct sampling stations were visited at various seasons between 2019 and 2021 to collect samples.

Physicochemical properties were quantified to analyze water quality fluctuation by season. Three seasons specifically pre-monsoon, monsoon and cool dry winter season's temperature, salinity, pH, DO, EC, TDS, and transparency were measured. The average temperature from the stations ranged from 24.16ºC to 27.4ºC. Mean seasonal temperatures for the pre-monsoon, monsoon and dry cool winter seasons are 26.83±0.21ºC, 27.06±0.22ºC, and 24.61±0.39ºC respectively. The salinity ranged from 24.42 ppt to 33.76 ppt, with the highest salinity (32.91±0.51) being measured in the pre-monsoon season. The value of pH was rather consistent throughout the year, ranging from 7.71 to 8.22, with the highest value (8.18±0.02) being measured in the pre-monsoon season. The amount of dissolved oxygen ranged from 4.82 to 6.74 mg/L, with the highest in the dry cool winter season (6.47±0.21 ppm) while the minimum dissolved oxygen was measured in the monsoon season (4.95±0.09 ppm). The value of electric conductivity ranged from 39.0 mS/cm to 53.46 mS/cm, with the highest value (52.06±0.90) being measured in the pre-monsoon season. The value of total dissolved solids ranged from

20.35 to 27.9 g/l, with the highest value (27.51±0.23) being measured in the pre-monsoon season while the lowest (20.98±0.35) was in the rainy monsoon season. The water around the island was clearer in the cool dry winter season with a range of 4.14±02 m. Furthermore, the water is least (1.45± 0.03) clear in the rainy season.

A thorough examination of the season resulted in the identification of 55 unique phytoplankton species. The overall number of phytoplankton ranged from 75,000 to 450,000 individuals per cubic meter, with the maximum abundance observed at station 10. *Coscinodiscus sp.* dominates all stations with cell densities of 12,500–87,500 ind/m^3 and other dominant species were *Chaetoceros*, *Thalassiosira*, and *Thalassionema.* Another investigation disclosed the presence of 34 distinct species of zooplankton. Most species were copepods, and station 8 had the most species. The observed range for the standing crop of zooplankton was between 55,000 and 125,000 individuals per cubic meter. Additionally, the community included Polychaeta and Cirripedia. The species of utmost significance encompassed *Oithona, Canthocalanus, Balanus, Euterpina,* and *Microsetella sp.* The levels of plankton abundance were found to be maximum during the pre-monsoon season, whereas moderately lower abundance was seen during the cool dry winter season.

All the nutrient concentrations exhibited highest mean values during the cool winter season (Nitrate: 0.673±0.074; Nitrite: 0.139±0.015; Silicate: 8.66±0.253; Ammonium: 0.275±0.046; and Phosphate: 0.165±0.029 mg/L) while during the pre-monsoon season the values were slightly lower (Nitrate: 0.336±0.041; Nitrite: 0.012±0.010; Silicate: 7.757±0.389; Ammonium: 0.163±0.046; and Phosphate: 0.120 ± 0.019 mg/L). During both seasons silicate and nitrate are the prime contributor of the nutrients followed by ammonium and phosphate, respectively. The study found that heavy metal concentrations (µg/L) for Lead (Pb) 76.825±37.91, Copper (Cu) 27.478±2.78, Arsenic (As) 0.990±0.19, Chromium (Cr) 3.475±1.92, Cadmium (Cd) 6.365±4.08 and Zinc (Zn) 44.534±12.09 in pre-monsoon hot season and for Lead (Pb) 24.909±9.28, Copper (Cu) 23.987±1.71, Arsenic (As) 1.0591±0.31, Chromium (Cr) 3.033±2.23, Cadmium (Cd) 3.727±1.26, and Zinc (Zn) 21.097±11.44 in cool dry winter season are still safe for any living organism.

Based on physiochemical qualities, plankton distribution, nutrients and heavy metal distribution, and pollution indexes (HPI, HEI, NPI, TERI), site, season and suitable species of fish and seaweed were chosen. As a result of the collective findings, it could be stated that the pre-monsoon season was strongly suitable for cage culture and cool dry winter season was strongly suitable for seaweed culture in the coastal waters of St. Martin’s Island. For cage culture, stations 10, 8 and 9 were selected to cultivate herbivore, omnivore and carnivore fish respectively, based on physiochemical attributes, nutrients, heavy metals and plankton abundance and distribution. On the other hand, based on physiochemical attributes, nutrient and heavy metal distribution station 1 was chosen for seaweed culture. However, it is also plausible to consider stations 10 and 12.

The suitability of mariculture in a coastal region is contingent upon a comprehensive assessment that considers various aspects, including environmental, economic, social, and regulatory concerns. In this study the benefit cost ratio (BCR) was taken into account as the basis of suitability of mariculture (BCR > 1 suitable, BCR < 1 unsuitable, BCR =1 marginally suitable).

According to the results of a thorough investigation of all of the studies, John’s Snapper (*Lutjanus johnii*), a carnivorous fish species was chosen as a representative species for cultivation and the monoculture technique of fish farming was used in this study. *Lutjanus johnii,* had a Benefit cost ratio (BCR) value of 1.1651 after being caged in coastal waters. BCR value showed that cage-growing of John’s Snapper at St. Martin's Island is profitable. The study suggests that the large- scale commercial cage culture of *L. johnii* has the potential to yield extremely significant profit.

Based on the comprehensive analysis of all the studies, *Padina gymnospora* (Brown algae) was selected as a commercially important algae to be cultivated in the coastal waters adjacent to St. Martin’s Island. BCR for *Padina gymnospora* was 2.75, using the long line method and 3.364 using the floating net method respectively which indicates cultivation of this species using both methods are profitable in the Island. BCR analysis also suggests that floating net culture is superior to long line cultivation for the purpose of growing seaweed. Nonetheless, the study suggests that cage and seaweed farming in St. Martin’s Island and adjacent coastal areas can promote the country's blue economy by increasing fish and seaweed production. Therefore, the cultivation of fish and seaweed in the coastal waters of the island has the potential to enhance the socio-economic well-being of the island's residents and contribute to the overall economic growth of the country. Water quality, diseases outbreak, habitat alternation, genetic homogenization, feed dependency, market volatility, technology and lack of regulations are some of the key limitations associated with mariculture research and practice. These limitations must be carefully considered and addressed to ensure the success of research efforts.

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Chapter 1 **Introduction**

Systematized evolution has enriched and endowed planet Earth with abundant resources. From the dawn of civilization, human beings have employed the best ways to know, use and protect these natural resources. For long, humankind has exploited nature to serve their own purposes. But it is a prerequisite to have in-depth knowledge of nature and its resources to ensure the optimal use. Only then the human being will be able to reap the maximum benefit out of these natural resources.

The land and the sea are two vital resources of nature. It is the coast where the sea and the land embrace each other. In order to adequately maintain, preserve, and maximize the benefits from the coastal environment, it is essential to understand its function in relation to the land and the ocean as well as its biodiversity. A healthy coastal system as a whole consists of coastal stability, beach replenishment, and nutrient regeneration that function to maintain ecological balance. Coastal areas also foster biodiversity and are rich in natural resources, offering a unique value proposition that has led to exploitation through processes such as urbanization, industrialization, transportation, business, and recreation. However, such interventions contributed to pollution, habitat destruction, and over exploitation of resources posed substantial threat and vulnerability to the natural system.

Many countries in the past century have undertaken coastal area development plans that were not properly coordinated and even in some cases were not included in the national development agenda. As a result, externalities of poorly planned shore development schemes heightened the vulnerability of wetlands, riparian forests, and estuarine ecosystems. Recurrent natural calamities like typhoons, severe inundation, and river basin erosion brought devastation that interrupted the normal way of life (Steffen & Walker, 1992). To tackle such issues, coastal zone management must factor both the man-made and natural interventions. In essence, it should balance the tradeoffs among competing socio-economic and political demands by integrating economic, environmental, and social concerns into the consideration. Scarcity of resources and competing values are two broad reasons why it is the time to adapt to integrated coastal zone management (Sorenson et al., 1990).

Not long ago, the quantification of environmental impacts of development activities used to be difficult to attribute. Consequently, the idea of conserving shorelines through adopting coastal zone management was arduous to be materialized. The introduction of environmental impact assessment in coastal studies in recent times has added a new dimension to the approach. (Klose, 1980) opined that establishing the cumulative impacts of a project is subjective. It has been severed owing to the deficiency of proper quantitative techniques. The proper allocation of natural resources is essential for safeguarding their sustainability. The approach to manage coastal area ensures such sustainability by defining the appropriate use of resources, allocating the methodical use by legal owners, and the conflict resolution among the stakeholders (Thia-Eng, 1993).

Munro (1991), suggests that proper synchronization among all the components provide the growth of an ecosystem. Planning and management are the two vital elements to manage a coastal area. Any disruption in managing all components is likely to upset the viability of the ecosystem. To achieve better guidance in this aspect recent research is targeting the need for more comprehensive measures. To keep the integrity of an ecosystem it is required to strike a balance between long-term and short-term solutions. In this sense, it is mandatory to grasp the physical and biological processes of these phenomena. Short-term solutions are enforced if there is a knowledge gap in understanding the dynamic forces acting between land and water (Winsemius, 1995). Such solutions may cause environmental and ecological instability due to fragility of execution and subsequent susceptibility arise from it. Volatile environment results in invasion and extinction of flora and fauna and intense changes in the use of resources and cause economic fluctuations.

Coastal areas bestow a better habitat to dwell in as it has better resource availability and favorable weather conditions. This can be corroborated by the percentage of world population census. Around 60% of the global population, or over 3.6 billion individuals reside in close proximity, specifically within a distance of 60 kilometers, to coastal areas. Based on the findings of the United Nations Environment Program (UNEP), it is anticipated that the aforementioned figure would see an upward trajectory, reaching 75% (equivalent to 6.4 billion individuals) by the year 2050. This surge can be attributed to heightened levels of migration from interior territories towards coastal locations. So coastal area of any country is very important and can play a vital role for promoting blue economy of the country.

The International Tribunal for the Law of the Sea (ITLOS) and the Permanent Court of Arbitration (PCA) of the United Nations both issued significant rulings on March 14, 2012, and July 8, 2014, respectively, affirming Bangladesh's entitlement to exclusive economic and territorial rights spanning 200 nautical miles in the Bay of Bengal (BoB). Bangladesh has been granted a significant portion of the outer continental shelf that extends beyond a distance of 200 miles as well as 70000 square kilometers of the total contested area of 80000 square kilometers with Myanmar in the eastern part of the Bay as a result of the tribunal's ruling. The court granted Bangladesh a territorial sea including St. Martin's Island that beyond its initial request, extending up to a distance of 12 nautical miles, making the ruling entirely favorable to Bangladesh. Accordingly, Bangladesh has a total size of 111,000 sq. km., including 41000 sq. km. before the subsequent ruling with India. The PCA, or Permanent Court of Arbitration, declined India's maritime claim, while simultaneously affirming Bangladesh's entitlement to a 200-nautical-mile exclusive economic zone (EEZ) and territorial rights within the Bay of Bengal (BoB). The ruling rendered by the international court based in The Hague resulted in substantial benefits for Bangladesh, as it granted the nation a considerable portion of the expanded continental shelf that extends beyond the 200 nautical mile limit. Bangladesh was given 19467 sq km of the contested 25602 sq km in the western half of the Bay by the tribunal. Bangladesh favors a fair strategy, whilst India and Myanmar favor an equal-distance method to acquire larger marine regions. The rulings guaranteed Bangladesh sovereignty over more than 118,813 square kilometers of waters, including its territorial sea, exclusive economic zone, and seabed, out to a distance of 354 nautical miles in the Bay. There are countless opportunities for resource development and scientific investigation given the existing 200-nautical-mile EEZ. The coastline area of Bay of Bengal in Bangladesh encompasses a total of 19 districts, 147 upazilas, and 111 nearby islands. Coastal areas of those districts and upazilas and the islands could be the most important area for exploring the possibilities of mariculture for promoting blue economy of those area as well as the whole country.

Codifying a national guideline for planning and managing the usage of coastal resources can be an effective strategy to tackle the problem by a country. The best management practices of coastal area should pay refined attention to reduce the adverse impact on coastal resources and ecosystems and use of the resources for economic growth of the country. It is also important to establish analytical frameworks and guidelines at both the national and local levels. This study uses the coastal area of St. Martin's Island in Bangladesh as a pilot area to develop and test a protocol for creating an analytical framework for assessing the potential of mariculture to promote the blue economy through effective use of coastal area in the region.

The intended study designed to articulate a framework to serve as a standard for exploring the possibilities of mariculture for promoting blue economy of St. Martin Island as well as the whole coastal area of the country in the Bay of Bengal region. This research first assesses the resources of St. Martin's Island and defines the components of sustainable development for coastal regions. It then analyzes the physical and chemical properties of the coastal water in different season to know about the present situation of the ecosystem. Then the abundance, diversity and distribution of phytoplankton, zooplankton, nutrient and heavy metal will be analyzed to determine the suitable season, site and species of fishes and seaweed for mariculture. Finally, the protocol will be applied to St. Martin's Island, the pilot study area of the Bangladesh coast to understand the probability of mariculture in that area.

The rationale for selecting the island as the research area is as follows: Generally, the islands are considered as closed systems. Islands can be suitable locations for implementing scientific and technical solutions for sustainable development, as they can be divided into "polygons" for applied research. Additionally, islands can be a good location for studying mariculture due to their size and location within the coastal zone. In addition, the externalities involving "continental" land use can also be minimized. The Island posits a unique geography and location for conducting research. It is also a suitable pilot model area as it has a copiousness and available means of data. St. Martin's Island is the only location in Bangladesh where coral colonies can be found, making it a biodiverse area that attracts many tourists. The island harbors various types of marine turtles that are globally endangered, and also functions as a resting place for migrating birds originating from the East Asian and Australasian regions throughout the winter season. The island holds significance not only due to its rich biodiversity, but also for Bangladesh in terms of establishing its Exclusive Economic Zone and determining its maritime boundaries in accordance with the United Nations Convention on the Law of the Sea.

The ocean is a vast and intimidating environment to do study, yet understanding its relationship with humans is critical. The Bay of Bengal is a tropical marine habitat that is semi-enclosed, located in southern Bangladesh, is a rich and diverse area that offers many opportunities for the discovery and development of marine natural products for various purposes, as well as for studying the ecological dynamics of coastal and deep ocean ecosystems, as well as the consequences of human activities on marine life. The beauty, mystery, variety of life in the water and economical possibilities of the ocean are typically what motivates me to perform this research.

1.1 Bay of Bengal

The Bay of Bengal is a geographical feature situated in the northern region of the Indian Ocean, spanning between the latitudes of 50°N and 22°N, and the longitudes of 80°E and 100°E. The region under consideration is geographically delineated by its western border, which is formed by the east coast of Sri Lanka and India. To the north, it is demarcated by the deltaic zone of the Ganges-Brahmaputra-Meghna River system, on the east by the Myanmar peninsula and connected to the Pacific Ocean on the south via the Australian wages. Bangladesh is located at the head of the bay. The southern edge of the bay is approximately delineated from Dondra Head, located in the southern region of Sri Lanka, to the northernmost point of Sumatra Island. The Bay of Bengal, which encompasses around 0.6% of the Earth's total oceanic area, is situated within a hydrologically balanced region. Following the decision with India and Myanmar, Bangladesh now has territorial sea in the Bay totaling about 118,813 sq. km, with 2,600 meters of average depth and 5,258 meters of maximum depth, extending 200 nautical miles from the country's coastlines. This Exclusive Economic Zone (EEZ) gives Bangladesh sovereign rights to explore and exploit the natural resources within this area, including fish stocks, oil and gas reserves, and minerals. In addition to the EEZ, Bangladesh also has a continental shelf area of approximately 66,438 square kilometers, which extends beyond the EEZ and further into the Bay of Bengal. The continental shelf refers to the submerged continuation of the landmass of Bangladesh, which holds considerable potential as a valuable reservoir of natural resources.

Overall, Bangladesh's maritime area is essential for the country's economy, particularly in terms of fisheries and potential offshore oil and gas reserves. The country is also actively engaged in exploring and exploiting the natural resources within its maritime boundaries while engaging in peaceful dialogue with neighboring countries to resolve any maritime disputes.

1.2 St. Martin's Island

St. Martin's Island in Bangladesh is a distinctive coral-bearing island renowned for its favorable natural circumstances, making it a highly sought-after tourist destination celebrated for its abundant biodiversity. The geographical location of the area is situated around 9 kilometers to the south of the Cox's Bazar-Teknaf peninsular point, and approximately 8 kilometers to the west of the northwest coast of Myanmar, in close proximity to the mouth of the Naf River within the Bay of Bengal. The island is geographically located within the latitudes of 20°34' and 20°39' N, and the longitudes of 92°18' and 92°21' E, making it the most southeastern point of Bangladesh. The island possesses a land area measuring around 5.9 square kilometers, which is further augmented by the presence of rocky platforms that extend into the surrounding water. Consequently, the total size of the island encompasses almost 8 square kilometers.

The island is characterized by five discrete physiographic regions, namely Uttar Para, Golachipa, Madhya Para, Dakhin Para, and Cheradia. The region known as Uttar Para is situated in the northernmost part of the island. It spans a maximum length of 2,134 meters in the north-south direction and a maximum width of 1,402 meters in the east-west direction. Golachipa is a sliver of land that connects Uttar Para and Madhya Para. Madhya Para, which is located directly south of Golachipa, is 1,524 meters long and 518 meters broad at its widest point. Dakhin Para is situated in the southern direction and spans a length of 1,929 meters. Additionally, it features a smaller extension of 1,890 meters towards the southeast. The width of Dakhin Para reaches 975 meters at its broadest point. Cheradia, the island's southernmost point, is a rocky reef that stretches south-southeast from Dakhin Para and is roughly 1.8 kilometers long and 50 to 300 meters broad. During high tide, it is separated from Dakhin Para, and three small vegetated islands known as Cheradia, the middle of which is the largest, are located on this inter-tidal reef (The study area was elaborately described in chapter 3). The sole coral-bearing island in Bangladesh's Bay of Bengal is St. Martin's Island. It is also one of the most biodiverse regions in terms of marine biota. The water around the island is also an ideal fishing zone as it is home to a variety of marine fish species. Approximately, 1650 MT of marine fish are caught every year (M. M. Hossain & Islam, 2006). The island is home to a diverse array of marine life, including 66 species of coral, of which 36 are currently living, 234 species of fish, 14 species of algae, and 187 species of crabs (M. M. Hossain & Islam, 2006). Approximately, 9 species of echinoderms, 4 species of Bryozoans, 61 species of mollusks, and 4 species of Zoanthids build up the macro- invertebrate communities of the island (Tomascik, 1997). The coastal waters of the island can be a potential zone for mariculture. There are nearly 7,000 people in St. Martin's Island area, with a slightly larger male population than female population. The majority of St. Martin's Island's residents are fishermen. Their primary job is fishing. During the dry season, they usually catch around 10,000 tons of fish. The average daily wage for a commercial fisherman is 500 Bangladeshi Taka. Female members always prefer to remain at home as housewives. Therefore, the cultivation of fish in the coastal waters of the island has the potential to enhance the socio-economic well-being of the island's residents and contribute to the overall economic growth of the country.

1.3 Physicochemical Properties of Coastal Waters

Water is one of the most important compounds in the ecosystem. From microscopic microorganisms to massive blue whales, water is essential for life. No known form of life could develop in the absence of water. Since all living things need water for survival, including animals and plants, water is often considered a universal marker of life. Seventy percent of Earth is made up of water in the form of rivers, lakes, seas, oceans, groundwater, and glacier all of which are essential to the cycle of life (Arimieari et al., 2014).

Sea water is a complex mixture of various salts, minerals, and organic compounds dissolved in water. Its physicochemical properties can vary depending on location, temperature, depth, and other environmental factors. Here are some of the general physicochemical properties of seawater:

Salinity: The salinity of seawater refers to the collective concentration of dissolved salts within the water, typically measured in parts per thousand (ppt) or practical salinity units (PSU). The mean salinity of seawater is around 35 parts per thousand (ppt) or 35 practical salinity units (PSU).

Density: The density of seawater is higher than that of fresh water due to its higher salinity and dissolved mineral content. The density of seawater also varies with temperature, pressure, and salinity.

Temperature: The temperature of seawater can vary depending on location, depth, and season. The temperature has the potential to exert a substantial influence on the distribution and behavior patterns of marine organisms.

pH: Seawater has a somewhat alkaline pH, typically falling within the range of 7.5 to 8.4. The pH can vary due to factors such as photosynthesis, respiration, and the dissolution of minerals.

Dissolved oxygen: Seawater contains dissolved oxygen that is essential for the survival of marine life. The amount of dissolved oxygen in seawater varies depending on temperature, salinity, and atmospheric conditions.

Carbon dioxide: Seawater also contains dissolved carbon dioxide, which can affect the acidity of the water and impact marine life. The amount of dissolved carbon dioxide in seawater can also vary depending on temperature, salinity, and atmospheric conditions.

Total dissolved solids (TDS): TDS in seawater refer to the amount of inorganic and organic substances that are dissolved in seawater. These include salts, minerals, metals, and other substances. The concentration of TDS in seawater varies depending on the location, depth, and temperature of the seawater. On average, the TDS concentration in seawater is around 35,000 parts per million (ppm) or 3.5% by weight.

Electrical Conductivity: The capacity of seawater to transmit an electrical current is determined by its conductivity. Seawater is a good conductor of electricity because it contains dissolved salts and other charged particles. The conductivity of seawater can vary depending on factors such as temperature, salinity, and pressure. Generally, seawater has a conductivity ranging from about 3.5 to 5.5 Siemens per meter (S/m) at a temperature of 25°C and a salinity of 35 parts per thousand.

Turbidity: Turbidity refers to the clarity or cloudiness of seawater, which can be influenced by factors such as suspended particles, algae, and organic matter.

Transparency: The transparency of seawater refers to how far light can penetrate through the water. This property of seawater is important because it affects the ability of marine plants to carry out photosynthesis and for fish and other animals to see and navigate. The transparency of seawater can be affected by several factors like turbidity, depth, temperature and salinity.

The marine environment, being a complex system, is predominantly influenced by a diverse range of physical, chemical, and biological events. The physical, chemical, and biological qualities of water can be used to describe its quality, which is a significant production limiting factor (Venkatesharaju et al., 2010). The change in water quality affects the biotic communities and the most sensitive species can act as an indicator. Various fish activities such as breeding, digestion, excretion, and reproduction are influenced by water quality. Moreover, fish production is greatly affected by water quality (Brönmark & Hansson, 2005). The quality of the water, however, affects more than just fish; every living thing has a set of ideal conditions for water quality within which they function most effectively. The bodily functions of the organism will be negatively impacted if any of these water's qualities alter (Davenport & Vahl, 1979). The monitoring of physicochemical characteristics of water is a crucial aspect in evaluating the water environment and ecology, as well as in the restoration of water quality (Islam et al., 2019; Sarkar et al., 2016; Whitehead et al., 2018)

Monitoring water quality is also essential for mariculture as the culture of fish requires an adequate, regular, and constant supply of good quality water. Bangladesh's coastal and marine waters consist of approximately 490 species of fish, 39 species of ray, 30 species of shark, 16 species of crab, and 28 species of shrimp. Marine species farming using cages in coastal waters could be an opportunity for the country's economy. However, no marine/coastal finfish are being farmed in the country's coastal waters (M. S. Hossain et al., 2014) The cultivation of marine organisms, including marine fish, shellfish, non-traditional species, and aquatic plants, within the coastal waters of Bangladesh is a nascent area of study. Culturing these organisms can lead to economic benefits and improved food security. Therefore, it is imperative to conduct an examination of the physicochemical characteristics of the water in close proximity to the island in order to ascertain its quality during various seasonal periods.

1.4 The Community of Plankton

The epipelagic zone, also known as the "sunlight zone," is powered by energy from the sun that is captured by photo synthesizers in the plankton, particularly phytoplankton. These minute creatures are of significant importance in the process of primary production within marine ecosystems. The terminology "plankton" was initially employed by Victor Hensen, a German marine researcher, in the year 1887. The term "plankton" originates from the Greek term "planktos," which translates to "to wander." This etymology is closely linked to the word "planet," as both words share a common source. The term "plankton" encompasses a diverse array of marine animals that exhibit a drifting or floating behavior in aquatic environments, rendering them incapable of actively propelling themselves against prevailing currents (Thurman & Burton, 1997) defined the plankton as those organisms that drift with ocean currents but all are not without the ability to move. Planktons have the ability to move, but they can either move very slowly or are limited to vertical mobility, making it impossible for them to identify their horizontal positions in the ocean. The plankton has traditionally been classified into phytoplankton (autotrophic) and zooplankton (heterotrophic). Phytoplankton include a wide spectrum of autotrophic creatures that are distantly related to algae, whereas zooplankton include micro-crustacea, rotifers, coelenterates, ctenophores, annelids, and mollusks.

Phytoplankton refers to the plants that live in the ocean's upper illuminated layer and follow this lifestyle (Thurman & Burton, 1997). Phytoplankton are free floating small plants that are typically unicellular and generate chemical energy from light in the euphotic zone, the sunny top layer of the water. Although the water in this zone makes up less than 2% of the world's ocean volume, it is vital to the survival of most pelagic marine life (Garrison, 2007). The aforementioned plants are primarily of microscopic size and fulfill a significant function in primary production, nutrient cycling, and food webs within aquatic ecosystems, constituting a substantial portion of primary production. (Dawes, 1998). Phytoplankton, which serve as the primary producers of organic matter in estuaries and oceans, play a crucial role in the aquatic food web by directly and indirectly facilitating the development of zooplankton, fish, and other marine species (Castro & Huber, 2003). Aquatic photosynthetic organisms have a crucial part in the production of fish and exert significant influence on changes in fish stocks. Their contribution to global carbon fixation exceeds 40% (Kankal & Warudkar, 2012) and reducing the impact of global warming. Additionally, According to estimates, phytoplankton is responsible for around 80% of the overall atmospheric oxygen production in certain regions, hence playing a crucial role in the preservation of oxygen-nitrogen equilibrium within the atmosphere (Castro & Huber, 2003). Marine algal flora occurs only about 2% of the entire ocean surface, at the narrow edges of the coastal areas. The vast ocean water, which contains around 98 percent oxygen and can reach depths of up to 200 meters (depending on latitudes, seasons, and water transparency), promotes the growth of phytoplankton, which is what makes up "Pasturage of the Sea" (Speight & Henderson, 2010)

Microscopic plants keep the globe warm, which raises the prospect of iron fertilization in the oceans. In salt marsh estuaries, despite the prevalence of vascular plant biomass over algae, phytoplankton can nevertheless provide a substantial contribution to the overall primary production. Diatoms, dinoflagellates, coccolithophorids, silicoflagellates, and photosynthetic bacteria are the other five major common types of phytoplankton present in the oceanic environment (Mann, 2000).

Zooplankton refers to animal plankters that inhabit the uppermost region of the ocean. While they possess the ability to move, their mobility is limited either due to physical constraints or a lack of capability to discern their horizontal positions within the ocean (Thurman & Burton, 1997). Zooplankton are widely recognized as occupying the initial trophic level, specifically that of primary consumers, during the transport of nutrients from phytoplankton through the grazing food chain across all oceanic ecosystems. Zooplankton efficiently preys upon phytoplankton throughout marine ecosystems, facilitating the transmission of energy from primary producers to various higher trophic levels along the food chain. These organisms possess the ability to either actively move or remain stationary, and they demonstrate vertical mobility as they align themselves with seasonal and tidal patterns to determine their horizontal locations within the water. Copepods make up the majority of zooplankton in terms of biomass, and their rate of feeding rises as phytoplankton abundance rises until a saturation density is reached (Speight & Henderson, 2010). Copepods aren't the only zooplankton that feed on phytoplankton; crustacean nauplii, euphausiids, and ciliate protozoa are further examples. Zooplankton, alongside phytoplankton, play a crucial role in the pelagic grazing food chain of marine ecosystems. Due to its profound influence on various operational components of aquatic ecosystems, such as food chains, trophic networks, energy transfer, and material circulation, zooplankton can be regarded as a very consequential biotic element. (Lampert, 1997) asserts that they possess a significant function within the food webs of the pelagic zone. Furthermore, because to their abbreviated life cycles and rapid adaptability to specific alterations in their surroundings, they can serve as valuable bioindicators (Ferdous & Muktadir, 2009)

Zooplankton grazers significantly reduce phytoplankton density; for instance, with a 20% grazing rate, they reduce phytoplankton population by 75% (Dawes, 1998). Zooplankton is a crucial part of the marine ecosystem and, because they are impacted by even the smallest environmental changes, they can serve as an early indicator of environmental hazards. Also, they exhibit variations in both their qualitative and quantitative characteristics as a result of the dynamics in the intensity of physical factors, acidity, and pollutants, as well as nutrients from farm runoff. The utilization of zooplankton data holds potential for the management and strategic planning of marine resources, the advancement of the fishing sector, and the preservation of the biogeochemical cycles within the ocean.

Zooplankton are categorized based on both their taxonomic classification and their size. Zooplankton exhibit a wide range of morphological variations, encompassing both minuscule unicellular entities such as protozoa and bacteria, as well as larger multicellular species including copepods, krill, and jellyfish. Certain types of zooplankton exhibit herbivorous feeding behavior by consuming algae and other types of tiny plants, whilst other types display carnivorous tendencies, as they prey upon fellow zooplankton or small fish. Zooplankton can be categorized into two primary classes according to their morphological characteristics.

Holoplankton: These creatures exhibit a life cycle wherein they remain as plankton throughout their whole developmental stages, starting from hatching till reaching adulthood. Examples of holoplankton include copepods, krill, and some types of jellyfish.

Meroplankton: These creatures exhibit a planktonic life stage throughout a portion of their life cycle. The larvae or eggs of these organisms have the ability to float within the water column, but ultimately, they undergo settlement on the ocean floor or attachment to a substrate in order to undergo maturation into their adult stage. Meroplankton encompasses various organisms such as the larvae of multiple fish species, sea stars, and crustaceans.

Zooplankton fulfill a crucial function in the regulation of the global carbon cycle by the ingestion and excretion of carbon-rich organic materials, as well as the transportation of nutrients from the ocean's surface layers to its deeper regions. They also help to control harmful algal blooms by consuming the algae responsible for these blooms.

1.5 Nutrients in the Ocean

The ocean contains numerous essential nutrients for the growth and survival of marine organisms. Oceanic nutrients include nitrogen, phosphorus, iron, calcium, magnesium, and potassium, among others. Nitrogen is a necessary nutrient for the synthesis of proteins and other organic compounds in marine organisms. Phosphorus is essential for the development and growth of marine organisms, particularly in the formation of bones and shells. Iron is required for the development of phytoplankton, which form the foundation of the marine food web. Calcium is essential for the formation of shells and skeletons in corals, mollusks, and crustaceans, among other marine organisms. Potassium is essential for the regulation of osmotic pressure and other cellular processes in marine organisms, while Magnesium is required for the formation of chlorophyll, which is essential for photosynthesis in marine plants. Overall, the availability of these and other nutrients in the ocean has a significant impact on the formation of marine ecosystems and the diversity of life within them.

Nutrients in ocean water are indispensable for biological productivity, management of aquatic ecosystems and living beings due to their engagement in multiple functional biochemical processes(Asanuma et al., 2014; Yang et al., 2018; M. Zhong et al., 2018; P. Zhong et al., 2017). Nutrients play their role from primary food producers, Phytoplankton to zooplankton. Primarily, phytoplankton use nutrients to generate amino acids, proteins, and associated substances that are then consumed by organisms higher up the food chain. But only minute amount of these nutrients is required for living organisms.

Excessive concentration of nutrients in the ocean water is alarming for the ecological components as they lessen the biological productivity and disturbs the biogeochemical processes results in nutrient enrichment or eutrophication of the coastal water (Asanuma et al., 2014; Chen et al., 2012; Glibert et al., 2010; Yang et al., 2018; P. Zhong et al., 2017) Eutrophication or nutrient enrichment triggers a series of manifestations, notably cyanobacterial blooms, jellyfish blooms, hypoxia, and ocean acidification (X. Sun et al., 2022). To check the nutrient enrichment in ocean water, it is obvious to track the source of nutrient and associated measures should be taken. The concentration of the nutrients may rise both for natural and anthropogenic purposes. In coastal or island regions, land and sea collide, resulting in nutrient enrichment as a natural cause. Moreover, while considering the anthropogenic sources, numerous sources are active to give rise the nutrient concentration in ocean water and sediment. Rapid urbanization, intensive use of fertilizer and pesticides for irrigation, water-based vehicle waste mixing with ocean water, and increased nutrient concentration in water are all contributing factors (Mbaye et al., 2016). Hence, assessing nutrient distribution, their concentration variations, and composition, as well as identifying the sources, is critical in order to use them as a theoretical and numerical framework for developing the required strategies for the conservation of ecological balance and ecosystem resilience.

In light of the significance of nutrients in mariculture, a comprehensive investigation was undertaken on St. Martin's Island, which is renowned for its diverse environment and unique status as the sole coral-bearing island in the Bay of Bengal. The island exhibits a significant endowment of natural resources and showcases a remarkable array of biological diversity. Specifically, it is home to a diverse range of organisms, such as 300 species of mollusks, 150 species of fish, 5 species of amphibians, 66 types of coral, 5 species of turtles, 5 species of snails, 200 species of birds, and 20 species of mammals (Ahmed, 1995). The environment of the islands includes various intertidal habitats consisting of both rocky and sandy areas, as well as subtidal habitats characterized by rocky formations. It supports a diverse array of plant and animal species, including a vast range of flora and fauna. Additionally, the ecosystem incorporates soft coral habitats and offshore habitats with soft-bottom substrates (M. Z. Islam, 2002; Thompson & Islam, 2010). Moreover, the island's geographic location aids nutrient accumulation since water from upstream transports a large volume of sediment and nutrients, which further flashes out to the ocean. Due to the rapid expansion of infrastructure and tourism on this island during the last several years, a substantial amount of pollution has been discharged into its coastal waters, which could be alarming for the biodiversity and environment of the islands. In this regard, integrated and systematic studies are required to assess the accurate and detailed distribution of nutrients, considering distribution, volume, and temporal changes.

The investigation of nutrient supply, geographical distribution, and rate of accumulation in relation to temporal variation has emerged as a significant area of research in coastal and estuarine ecosystems, owing to their considerable significance. Previously, the majority of the research was conducted on temporal and spatial variation in different parts of the world (Wang et al., 2012; Yang et al., 2020; K. Sun et al., 2015). Several studies on some ecological disasters like hypoxia, eutrophication, and algae blooming were carried out. Some limited approaches for nutrient distribution were taken in the coastal areas of the Bay of Bengal, but no significant approaches for nutrient distribution were taken on St. Martin Island. In this study, a deterministic approach was taken on St. Martin Island that is the inaugurating research endeavor in the location. As a small part of the present study, nutrient variation at the circumference of the island's shoreline was assessed and portrayed in the map. The seasonal variation of nutrients was then enumerated in order to understand the rate of nutrient accumulation.

1.6 Heavy Metals in the Ocean

Heavy metals encompass a category of metallic elements characterized by their elevated atomic weights, which render them potentially harmful to both humans and other living beings when present in specific concentrations. The amount of heavy metals in a specific sample or item, whether water, soil, food, or blood, is referred to as the heavy metal concentration. Some of the common heavy metals found in the ocean include Lead (Pb), Mercury (Hg), Cadmium (Cd), Arsenic (As), Chromium (Cr), Copper (Cu), Zinc (Zn), Nickel (Ni), Aluminum (Al) and Iron (Fe). These heavy metals can come from natural sources, such as geological deposits, as well as human activities, including industrial processes, mining, and waste disposal. It's important to monitor the levels of heavy metals in water to ensure the health of aquatic ecosystems.

Prominent heavy metals that elicit worry encompass lead, mercury, cadmium, arsenic, and chromium. The quantification of heavy metal levels is commonly conducted using units of parts per million (ppm) or parts per billion (ppb). Environmental regulations and health guidelines have been established for acceptable levels of heavy metal concentration in different substances, and monitoring is typically conducted to ensure that these levels are not exceeded.

The potential health implications of being exposed to elevated quantities of heavy metals are of significant concern, including neurological damage, cancer, and organ damage. Hence, it is imperative to diligently observe and regulate the levels of heavy metals in order to safeguard the well-being of individuals and the ecological balance. Heavy metals can enter the ocean through a variety of natural and human-related sources such as weathering of rocks, volcanic activity, mining, industrial discharges, and runoff from agricultural and urban areas. Once in the ocean, heavy metals can accumulate in sediments, plankton, and other marine organisms, potentially leading to toxic effects on marine life and humans who consume them.

Several heavy metals, such as mercury, lead, cadmium, copper, and zinc, are frequently encountered. Mercury, specifically, poses a significant problem due to its potential conversion into methylmercury, a highly poisonous variant that has the ability to bioaccumulate within the food web, resulting in elevated levels of exposure for apex predators like tuna and swordfish. This can have serious health implications for humans who consume these fish.

Heavy metal concentrations in the sea can vary depending on a variety of factors such as proximity to industrial activities, shipping lanes, and natural geological processes. Human activities such as industrial discharge, agricultural runoff, and oil spills can introduce heavy metals into the ocean. Heavy metals can also be released into the atmosphere through burning fossil fuels and then eventually deposited in the ocean through rainfall or other processes.

The establishment of standards by the World Health Organization (WHO) for acceptable levels of heavy metals in drinking water is a well-documented initiative. However, it is worth noting that at now, there is a lack of internationally recognized rules pertaining to the permissible amounts of heavy metals in saltwater. Nevertheless, some entities and nations have developed their own protocols pertaining to acceptable thresholds of heavy metal concentrations in seafood. These standards serve as a means to assess the presence of heavy metal pollutants in marine environments.

Efforts to reduce heavy metal pollution in the ocean include implementing regulations and policies to reduce industrial and agricultural discharges, improving wastewater treatment systems, and promoting sustainable fishing practices. Additionally, individuals can help by properly disposing of hazardous household waste and reducing their use of products containing heavy metals.

1.7 Mariculture for Promoting Blue economy

The blue economy refers to the responsible and sustainable utilization of marine resources with the aim of promoting economic development, enhancing quality of life, and generating employment opportunities, all while ensuring the preservation and well-being of the marine ecosystem (World Bank, 2017).

The term "blue economy" refers to the practice of using ocean resources in a way that promotes economic development, better quality of life, and job creation while protecting the wellbeing of marine and coastal ecosystems. Bangladesh has a lot of potential for the growth of a blue economy due to its large coastline along the Bay of Bengal.

The fishing industry, shipbuilding, tourism, and offshore energy are the primary sectors of Bangladesh's blue economy. The largest source of animal protein for the nation's population and a substantial source of foreign exchange revenues is the fisheries industry. To protect fish stocks, the government has launched a number of programs to encourage sustainable fishing methods and minimize illicit fishing.

Bangladesh's shipbuilding sector is expanding quickly, and the nation is quickly emerging as a top location for the outsourcing of shipbuilding and maintenance services. The sector has increased employment and substantially raised the GDP of the nation.

The natural attractions of Bangladesh, including its beautiful beaches, coral reefs, and mangrove forests, offer significant potential for the development and expansion of the country's tourism industry. In order to attract both local and international tourists, the government has implemented measures to enhance the facilities and infrastructure in various tourism destinations. Last but not least, Bangladesh offers enormous potential for the development of offshore energy, particularly in the form of wind and wave energy. The national dependency on fossil fuels has been lessened thanks to government initiatives to promote renewable energy sources. Overall, Bangladesh's economic growth and development might benefit significantly from the Blue Economy while maintaining the viability of the nation's marine and coastal ecosystems.

The government of Bangladesh has identified the blue economy as a priority area for economic development, and various initiatives have been taken in this regard. A comprehensive list of 26 sectors pertaining to the development and economic growth of the blue economy has been compiled for the optimal usage of oceanic resources within Bangladesh's existing maritime boundary. Among these sectors, 12 have been selected as major sectors, with Marine Fisheries and Aquaculture being included in this priority group. The aforementioned sector exhibits significant potential for generating overall economic benefits and fostering livelihood development. This study explores the possibility of implementing a sustainable blue economy with an emphasis on mariculture.

Mariculture encompasses the practice of cultivating, managing, and collecting marine species inside their native habitats or within confined structures such as cages, pens, tanks, or channels. This includes various types of water bodies, such as estuarine, brackish, coastal, and offshore environments. It has the potential to be a significant contributor to Bangladesh's economy, providing employment opportunities and a source of seafood. The mariculture industry in Bangladesh exhibits substantial growth potential and holds the capacity to contribute significantly to the nation's economic advancement. The range of organisms cultured includes - Fish, Seaweeds, Crustaceans, Mollusks and Echinoderms. In this study, fish culture in cage/ Cage culture and Seaweed culture was focused.

1.8 Cage Culture in the Coastal area of Bangladesh

Bangladesh is a land with abundant opportunity. Despite its size of around 147,570 square kilometers, it is home to approximately 169.11 million individuals (BER, 2022). Agriculture comprises 11.50 percent of Bangladesh's gross domestic output, whilst fisheries comprise 2.51 percent (BER, 2022). 11 percent of the world's population relies on fisheries for sustenance (M. S. Hossain et al., 2014). As the importance of agriculture to the national economy declines, new and inventive agricultural practices may lead us to uncharted territory. Aquaculture is considered a sustainable way of life in the 21st century. Aquaculture encompasses the practice of cultivating various aquatic species and plants, including but not limited to fish, mollusks, crabs, and aquatic plants. To enhance production, farming involves intervention during the rearing period, including regular stocking, feeding, and predator prevention, among other measures. Farming entails individual or corporate ownership of the animals farmed. Aquatic creatures gathered by a person or entity that owned them during their growth phase are classified as aquaculture, whereas aquatic species exploitable by the public as a common property resource, with or without a license, are classified as fisheries harvest (FAO, 1998). Due to unsustainable overfishing in wild fisheries, there is a growing demand for fish and fish protein. The fisheries resources of the nation can be classified into three distinct categories: inland aquaculture, inland capture fisheries, and marine capture fisheries. Notably, inland aquaculture contributes to almost 55 percent of the overall production (DoF., 2016). The fisheries sector makes a significant contribution of 3.52 percent to the overall gross domestic product of the nation, as well as accounting for 26.37 percent of the agricultural GDP (FRSS, 2021).

According to the data provided by the Fisheries Resources Survey System FRSS in 2021, Bangladesh exhibited a total fish output of 4,503,371 metric tons over the period of 2019-2020. This production was comprised of 1,248,401 metric tons from inland capture fisheries, 2,583,866 metric tons from inland aquaculture, and 671,104 metric tons from marine water production. There has been a significant augmentation of fish production, amounting to a multiplication by a factor of six, within the past three decades. Inland culture fisheries encompass several methods such as pond/ditch, ox-bow Lake (baor), shrimp/prawn farm, seasonal cultured water-body, pen and cage culture, among others. These practices span around 8.37 lakh hectares and yielded a production of 25.84 lakh metric tons in the fiscal year 2019-2020, constituting approximately 57.38 percent of the overall fish output. According to the FRSS (2021) there has been a notable increase in aquaculture production, with output rising from 10.63 million metric tons in the period of 2008-2009 to 25.84 million metric tons in the period of 2019-2020. This data indicates a sustained pattern of expansion in the aquaculture industry.

It is possible to grow fish extensively and intensively. Various types of fish farms, each with their own benefits and applications, are used in intense and extended aquaculture technologies. This category encompasses many aquaculture technologies, namely cage systems, pond systems, composite fish culture, integrated recycling systems, and conventional fry farming. Presently, researchers and commercial producers are placing a greater emphasis on cage cultivation. Due to factors such as rising fish consumption, dwindling wild fish populations, and unstable farm economics, the production of fish in cages has gained popularity. Very small or marginal farmers seek alternatives to conventional agricultural goods. Aquaculture looks to be a rapidly growing business with limited growth potential. Additionally, cage culture helps the farmer to utilize current water supplies, which are sometimes limited in their applications.

Cage aquaculture is the practice of raising fish in existing water bodies using floating net cages. It is a production system that includes a floating frame, net materials, and a mooring system (such as ropes, buoys, and anchors) in the form of circular or square floating nets. These cages can be deployed in reservoirs, rivers, lakes, or oceans to cultivate large numbers of fish. The cage system is enclosed by a catwalk and railing. This method of aquaculture is relatively low-impact, generates high yields and emits little CO_2. By using existing bodies of water, the need for a consistent supply of clean and oxygenated water, a major limitation of land-based fish farming, is eliminated. The layout of cage farms makes use of the currents that occur naturally, which give fish oxygen and other essential conditions.

Due to the high production levels that may be attained, cage culture in the coastal area has the potential to significantly contribute to Bangladesh's fish supply. Cage culture may be used to maximize the utilization of Bangladesh's enormous coastline, the vast brackish water regions accessible to coastal states, and other underutilized water bodies. This farming practice is useful as a supplemental source of income for small-scale fishermen since it requires less investment and little area. Because the labor required is little and manageable by a small household, this might be a home activity. The design and attachments of the cage are adaptable to the specific needs of each farmer.

Although there is sufficient chance for marine cage culture due to the country's lengthy coastline along the Bay of Bengal, this technology is still not frequently utilized. There are currently only 3,000 marine cages in use along the coast, according to Bangladesh's Department of Fisheries. Seabass, grouper, snapper, pompano, and cobia are the most frequently farmed species in marine cage culture in Bangladesh. The majority of these fish are exported to nations like China, Hong Kong, and the Middle East. Despite the growth of the industry, there are some concerns about the environmental impact of marine cage culture in Bangladesh. The concentration of fish waste and uneaten feed beneath the cages can lead to pollution and the depletion of oxygen in the surrounding waters. There have also been incidents of fish escaping from the cages and potentially competing with wild fish populations. Efforts are being made to address these concerns through the development of better management practices and regulations. The government of Bangladesh is also investing in research and development to support sustainable growth of the marine aquaculture industry.

1.9 Seaweed Culture in the Coastal area of Bangladesh

Seaweed culture, also known as seaweed farming or mariculture, is the cultivation of seaweed for commercial or personal use. In Bangladesh, seaweed culture has the potential to become a significant industry due to the country's vast coastline and rich marine biodiversity. Bangladesh's coastline region provides a favourable setting for the cultivation of seaweed. Seaweed may grow well in the warm, salty, and nutrient-rich environment that the Bay of Bengal offers. Seaweed farming can benefit coastal areas by generating employment opportunities and boosting the local economy.

According to specialists, this coastal region's estuaries, mangrove swamps, and sandy and muddy shores offer foundations and ecosystems for the production of several species of seaweed (Siddiqui et al., 2019). The coastal region of Bangladesh provides a suitable substrate and habitats for the production of several seaweeds, along with sandy and muddy beaches, estuaries, and mangrove swamps. There are 133 varieties of seaweed in Bangladesh, 14 of which are prominent economically (Siddiqui et al., 2019). In several south-east Asian nations, seaweed cultivation is well advanced. Additionally, the biochemical, pharmaceutical, and cosmetics industries use seaweed as a constituent. However, Bangladesh's seaweed sector is still in its infancy. If carefully cultivated and investigated, seaweed might become a crucial agricultural commodity for coastal areas, be utilized in food preparation, be employed in the pharmaceutical and cosmetics sectors, and boost the country's economy.

Seaweeds, also known as marine macroalgae, are plant-like creatures that often inhabit coastal environments connected to rock or even other hard sedimentary layers (Kılınç et al., 2013). It often grow in coastal areas and come in a wide variety of sizes, colors, forms, and compositions. It can be cultivated through various methods, including the use of ropes or nets to grow the seaweed on the surface of the water or by attaching the seaweed to a structure such as bamboo or plastic frames. Different types of seaweed can be grown, including red, green, and brown varieties. Red and brown seaweed are commonly used for food, while green seaweed is used for other products such as cosmetics and medicines. Green algae, red algae and brown algae are known as Chlorophyceae, Rhodophyceae, and Phaeophyceae respectively (Evans & Critchley, 2014).

There are seaweeds thriving in the world's oceans and seas, and none have been shown to be hazardous (Bold & Wyne, 1985; Lobban & Harrison, 1994; Soler-Vila et al., 2009). In marine aquatic food webs, seaweed is a key major source. They are a rich commodity for the cosmetics and pharmaceutical industries, as well as minerals and important trace elements (Bernays & Chapman, 1970). For around 14,000 years, man has used seaweed as food and medicine. A significant aquaculture business, notably in Asia, has been fuelled by the continuously growing need for edible seaweed and for the bioactive metabolites of seaweed, primarily refinished products like agar, alginate, and carrageenan (Buchholz et al., 2012).

Bangladesh's seaweed culture suffers a number of obstacles, such as a lack of understanding and training in seaweed farming methods, restricted access to financing, and a lack of a market for seaweed goods. Seaweed cultivation, however, has the potential to develop into a prosperous business in Bangladesh, benefiting coastal people economically and encouraging the sustainable management of marine resources.

1.10 Significance of this Study

St. Martin’s Island is an important biological habitat for wildlife, particularly seaweeds and other flora and fauna. Although it is slightly explored and unfortunately there is no information about commercially important seaweed and cage culture in that area. This is situated slightly far from the mainland of Bangladesh and there are several challenges for commercially important seaweed and cage culture. The suitable season, suitable site depending on physicochemical properties of water, plankton abundance, nutrient and heavy metal distribution, method of culture and suitable species for cultivation are also unknown in this island. Mariculture can play a vital role for resolving the lack of nutrients among the local people and it can also improve the socio-economic condition of the local unemployed people by creating alternative job for them. Sustainable mariculture practices can help alleviate the pressure on wild fish stocks, which are already under threat due to overfishing, habitat destruction, and climate change. By reducing the need for wild-caught fish, mariculture can help reduce the impact of fishing on marine ecosystems and protect endangered species. St. Martin's Island is designated as an Ecologically Critical Area (ECA), and vulnerable to a number of threats. These threats include overexploitation, ghost fishing, global warming, coral bleaching, and the effects of climate change. The current state of St. Martin’s Island must be analysed in order to determine the status of mariculture, as well as the feasibility to successfully employ it for promoting blue economy of that area. The study of mariculture is significant because it can contribute to sustainable development, food security, environmental protection, and scientific knowledge.

1.10.1 Objectives

- To study the feasibility and suitability of cage culture-specifically determining the suitable Season, Site and Species of fish for cage culture in the island
- To study the feasibility and suitability of seaweed culture–specifically determining the suitable Season, Site and Species for seaweed culture in the island
- To create alternative source of income for unemployed people of the island by implementing Cage and Seaweed culture

And finally prepare a framework to determine the possibility of mariculture to promote blue economy of the St. Martin’s Island. In order to reach the study objectives, the following investigations are required in different seasons of the year:

- Analysis of the physicochemical properties of the coastal waters
- Determination of the abundance and distribution of plankton
- Determination of the abundance and distribution of nutrients and
- Determination of the quantity and distribution of heavy metals

The investigation of the physicochemical properties of water, as well as the abundance and distribution of plankton, and the spatial distribution of nutrients and heavy metals, will aid in the identification of appropriate locations, seasons, and fish species for cultivation in the coastal waters of St. Martin's Island. Similarly, the analysis of the physicochemical properties of water and the spatial distribution of nutrients and heavy metals will assist in determining the suitable site, season, and species of seaweed that can be cultivated in the same area.

Chapter 2 **Literature Review**

This chapter provides a literature review on various methodologies used for gathering the data of phytoplankton, zooplankton, physicochemical properties of water and the extraction of nutrients and heavy metals in the seawater protocols for marine biota from national and international studies. The literature on blue economy, seaweed and cage culture from national and international studies also reviewed in this chapter.

2.1 Introduction

The abundance, distribution and seasonal variation of physicochemical properties, phytoplankton and zooplankton and spatial distribution and seasonal variation of nutrients and heavy metal helps to determine the suitable site, season and the species of fish and seaweed that can be cultivated in the coastal waters of St. Martin’s Island but such kind of information was not available and research on those areas has not done yet. Related information could be found in different part of the Bay of Bengal and other part of the world.

2.2 Physicochemical Properties of Water

For every living thing, water is very necessary. In our surroundings, it comes in a variety of forms. It is challenging to properly comprehend biological phenomena without knowledge of the quality of the water, as the chemistry of water discloses much about the ecosystem's metabolism and explains the basic hydro-biological connection. Water is an essential environment for life on Earth, and its physico-chemical characteristics play a critical role in supporting all living processes. It is one of the most important compounds in the ecosystem. From microscopic microorganisms to massive blue whales, water is essential for life. No known form of life could develop in the absence of water. Since all living things need water for survival, including animals and plants, water is often considered a universal marker of life. Seventy percent of Earth is made up of water in the form of rivers, lakes, seas, oceans, groundwater, and glacier all of which are essential to the cycle of life (Arimieari et al., 2014).

Understanding the interactions between different levels of the aquatic food web and the water itself requires a thorough understanding of hydrology. In wetland and coastal habitats, maintaining good water quality is vital for the survival of aquatic communities. Coastal marine ecosystems are among the world's most productive and diverse, and their rich biodiversity can be attributed to their proximity to land. These environments typically have more biodiversity than open ocean regions. Seawater's physical and chemical characteristics have a significant impact on organisms, and this impact varies significantly depending on the size of the organism.

Due to its importance for both human health and socioeconomic growth, coastal water has become a serious concern. The growth of human populations and commercial industries has led to increased pollution of seawater from various sources such as sewage discharge, fish farming, waste disposal, and recreational activities. The impact of human activity on water quality and aquatic ecosystem functioning is already apparent. The presence and abundance of aquatic species are affected by physicochemical factors. The intricate interaction of physical, chemical, and biological processes within coastal habitats yields a heightened level of biodiversity and ecological abundance. The number of nutrients affects how fertile the water masses may become, so it's important to gather information on their distribution and behavior in various coastal ecosystems. Understanding the interactions between the organism and the functioning of the coastal ecosystem is crucial. Many researchers have investigated the Physicochemical properties (Perumal et al., 2009; Prasanna & Ranjan, 2010; Sridhar et al., 2006). The most crucial resource for providing a stable foundation for coastal life is the coastal environment, which is a thriving host for fauna and plants.

The marine environment, being a complex system, is largely influenced by a diverse range of physical, chemical, and biological events. The physical, chemical and biological qualities of water can be used to describe its quality, which is a significant production limiting factor (Venkatesharaju et al., 2010). The change in water quality affects the biotic communities and the most sensitive species can act as an indicator. Various fish activities such as breeding, digestion, excretion, and reproduction are influenced by water quality. Moreover, fish production is greatly affected by water quality (Brönmark & Hansson, 2005). The quality of the water, however, affects more than just fish; every living thing has a set of ideal conditions for water quality within which they function most effectively. The bodily functions of the organism will be negatively impacted if any of these water's qualities alter (Davenport & Vahl, 1979). So, monitoring the physicochemical parameters of the water plays an important role in the assessment of the water environment, and ecosystem, and in restoring the quality of the water (Islam et al., 2019; Sarkar et al., 2016; Whitehead et al., 2018).

Monitoring water quality is also essential for mariculture as fish and seaweed culture requires an adequate, regular, and constant supply of good quality water. Bangladesh's coastal and marine waters consist of approximately 490 species of fish, 39 species of ray, 30 species of shark, 16 species of crab, and 28 species of shrimp. However, no marine/coastal finfish are being farmed in the country's coastal waters (Hossain et al., 2014). Coastal and Sundarbans mangrove areas of Bangladesh are also abundant with seaweeds. About 200 species of seaweed have been reported from Bangladesh's coastal areas (Aziz, 2011; Islam et al., 2019).

2.3 Abundance and Distribution of Planktons

The Bay of Bengal, located in the southern region of Bangladesh, is a semi-enclosed tropical marine ecosystem that is rich in coral ecosystems and marine life. This vast area encompasses deep ocean habitats and coastal zones and provides insight into how marine life is affected by human activity. BoB's estuaries and oceans are home to phytoplankton, which is the main producer of all organic compounds. The creation of zooplankton, fish, and other living species is aided directly and indirectly by all of them, which connect the marine aquatic food chain (Castro & Huber, 2003). According to Kankal & Warudkar (2012), phytoplankton contributes more than 40% of the world's carbon fixation, which reduces the global warming factor and is a key biological factor in fish supply fluctuations. According to estimates, phytoplankton generates almost 80% of the total atmospheric O_2 in some regions, which accounts for the air's O_2:N_2 balance (Castro & Huber, 2003). Furthermore, the presence of phytoplankton can serve as an indicator of water quality, which may be negatively affected by human activities such as the disposal of household and industrial waste, and activities that lead to nutrient enrichment (Carter et al., 2005; Vitousek, 1997).

In Bangladesh, nothing much is known about marine phytoplankton yet. Nevertheless, it has been the subject of a few papers from the BoB's northeastern shore and the Karnafuli estuary (A. Islam & Aziz, 1975). Researchers from Ahammed et al. (2016), Ahmed et al. (2010) and Aziz et al. (2012) examined the phytoplankton variety along Bangladesh's south-western coast. Rahman et al. (2014) also investigated how coastal phytoplankton changes with the seasons (2013). The only coral island is St. Martin's Island, which is located on the far southern edge of Bangladesh's main area. The island is quite appealing to visitors for vacation purposes. As a result, anthropogenic activities have a significant impact on the island's shore line as well as the nearby marine open waters. The local economy of the island is greatly impacted by the fishing and tourist industries, bringing in an estimated 33.6 million USD per year. Fishing alone contributes a direct revenue of 13 million USD annually (Rani et al., 2020). The utilization of data on phytoplankton can provide valuable insights for the planning and management of fisheries and marine resources, as well as contribute to the preservation of ocean biogeochemical cycles.

The changes in phytoplankton biomass over time are the result of a combination of various factors such as physical, chemical, and biological processes. There is a wide range of information available on phytoplankton abundance and species diversity but a little information or some studies have been carried out on phytoplankton abundance in an around of Bay of Bengal of Bangladesh. It is very important to review the past research works before conducting any experiment.

According to Asha et al. (2018), the distribution and diversity of phytoplankton species were examined in the coastal waters of Tuticorin, India, based on their physical and chemical characteristics. In the inshore waters of Tuticorin from January to December 2008, a study was done to assess the phytoplankton community structure and its association with specific physicochemical characteristics. The research vessel Cadalmin IV collected water and plankton samples from the surface seas at two depths (5m and 10m). For phytoplankton identification, enumeration, and assessment of physicochemical characteristics, standard procedures were used. The study identified 69 species of phytoplankton, with diatoms dominating 85.5% of them and dinoflagellates 14.5%. With a mean of 2.14 104 0.4 104 cells/L and 3.37 104 0.9 104 cells/L at 5 m and 10 m depths, respectively, the overall phytoplankton density was significantly greater at 10 m. According to the analysis, algae species are more diverse at 10 m depth during the monsoon season than they are at the same depth during the post-monsoon. It is confirmed that seasonal variations in the physicochemical variables have a greater impact on phytoplankton population density than other factors, especially given the impact of the northeast monsoon in the inshore waters of Tuticorin, India.

In the Eastern Obolo River Estuary of the Niger Delta, Effiong et al. (2018) reported on the spatial distribution and diversity of the phytoplankton population. In this study, the diversity, distribution, composition, and physical and chemical properties of phytoplankton in the Eastern Obolo River Estuary were analyzed over a period of two seasons from June to November 2015 and December to May 2016. The number of phytoplankton was directly correlated with water conductivity, and species density was strongly correlated with turbidity. At three stations, species were more uniformly distributed during the dry season, and unevenly distributed during the wet season. The Shannon-Wiener index (H) demonstrated significant variability across different locations and seasons. The diversity index (D) for both seasons at station 2 was found to be the lowest in the case of Simpson. During the rainy season, a total of 5109 unique species, 85 taxa, 16 orders, 8 classes, and 5 divisions of phytoplankton were observed. In contrast, the dry season exhibited a higher diversity with 6906 distinct species, 84 taxa, 18 orders, 6 classes, and 4 divisions. During the dry season, the relative abundance of phytoplankton followed the order: Bacillariophyta (79%), Cyanophyta (12%), Chlorophyta (7%), and Dinophyta (2%). During the rainy season, the dominant phylum seen was Bacillariophyta, accounting for 60% of the total. This was followed by Chlorophyta at 22%, Cyanophyta at 15%, Dinophyta at 3%, and Euglenophyta at 0%. In both seasons, Bacillariophyta exhibited dominance in terms of both abundance and species composition.

According to Shoaib et al. (2017), a qualitative and quantitative assessment was conducted on the phytoplankton population found in the mangrove ecosystem of Sandspit, Karachi. (2017). The morphologies of diatom species appeared to be more diversified and predominate. On the other hand, samples collected in June, August, and September contained dinoflagellates, which had very little species diversity. The range of phytoplankton cell density during high and low tide was 0.25 106 to 7.044 106 and 0.042 106 to 5.172 106 cells per L, respectively. When compared to centric diatoms, pennate diatoms were much more diverse (3 centric and 23 pennate). The most frequent species in the pennate group were *Cyilndrotheca closterium, Navicula sp., Nitzschia sp., Pleurosigma sp.,* and *Gyrosigma sp*., in that order. Cyclotellan meneghiniana dominated the centric diatom community. Only a few dinoflagellate species were discovered, including *Gyrodinium spirale, Prorocentrum micans,* and *Alexandrium sp.* Salinity (33-42 PSU), temperature (16-32 °C), pH (7.0-7.7), dissolved oxygen (0.08-6.18mg/L), total suspended solids (0.97-13.8mg/L), and chlorophyll a (0.0006-0.431 g/L) data ranges were also noted. Throughout the course of this experiment, the Layari River significantly polluted Sandspit backwaters, which led to the predominance of resistant diatom species and the appearance of dinoflagellates in very low abundances and variety.

The primary focus of the study conducted by Dash et al. (2016) was the examination of hydrology and phytoplankton variety in the Dhamra coastal water located on the eastern coast of India in the Bay of Bengal. A study was conducted between July 2015 and March 2016 in the coastal waters of Dhamra, located in the Bay of Bengal. The objective of the study was to evaluate the variations in physicochemical parameters and plankton diversity throughout this period. Throughout the duration of the investigation, various parameters were examined to assess water quality. These parameters included sea surface temperature (SST), pH levels, transparency, dissolved oxygen levels, salinity, sulphate concentrations, and nutrient levels such as silicate, phosphate (both orthophosphate and total phosphate), nitrite, and nitrate. Additionally, the variety of the plankton and its relationship to other hydrological factors received significant attention. During the study period, differences in plankton diversity and water quality were detected. The SST value ranged from 26.88°C in March to a maximum of 30.39°C in the month of September. While the pH reached its highest point in July and its lowest point in March, 8.19 and 7.52 respectively, the study found that water transparency ranged from 1.04 meters in July to 2.71 meters in November. Maximum and minimum levels of dissolved oxygen, or 7.25 mg/l and 3.49 mg/l, respectively, were recorded in September and March. The research found that SST and dissolved oxygen were directly proportional. Similarly, Salinity was found to be inversely connected to SST and was at its highest during the summer month of March (32.07 ppt), when evaporation was at its highest. On the other hand, September marked its lowest point (15.62 ppt). While the total phosphate content ranged from 0.081 to 0.153 mg/l, the orthophosphate concentration ranged from 0.057 to 0.139 mg/l. Silicate concentrations ranged from 13.75 to 45.35 g/l, while sulphate concentrations ranged from 269.37 to 558.98 mg/l. Nitrate and nitrite, which have concentrations ranging from (5.52-77.79 M/l) and (1.56-5.58 M/l), respectively, are two important sources of nitrogen. A total of 17 phytoplankton species were identified from the sampling locations.

Naz et al. (2013) conducted a study in the coastal waters of Karachi, Pakistan, with the objective of examining the distribution and abundance of diatom species. To date, there has been limited knowledge regarding the spatial distribution and population density of diatom species inhabiting the coastal and near-shore waters adjacent to Karachi, Pakistan, which is situated along the northern region of the Arabian Sea. There are 20 genera in all that are widely distributed. At all sites, *Guinardia, Chaetoceros, Leptocylindrus, Nitzschia,* and *Lennoxia* were the most prevalent genera. High levels of abundance at the Manora coastal station (MI-1) were correlated with high levels of chlorophyll (130 gL-1). At Mubarak Village Coastal Station, the lowest abundance and lowest chlorophyll a value (0.05 gL-1) were noted (MV-1). Significant link between diatom abundance and chlorophyll a was found. The present research revealed a total of 12 centric forms and 8 pennate forms, indicating a comparable level of variation between the two groups. A comprehensive analysis reveals the existence of a grand total of 134 distinct species. Among them, 40 species were detected exclusively at four locations, while

31 species were observed only at three stations. Additionally, 23 species were spotted at two stations, and 40 species were observed at only one station. The abundance of phytoplankton and diatoms reached their maximum during the Northeast (NE) monsoon, coinciding with the occurrence of upwelling events off the coast of Oman in the Southwest (SW) monsoon season, which typically takes place during the winter season. The Manora coastal and nearshore sites (MI-1, MI-2) exhibited a higher level of diversity, which suggests that there is an impact from the organic pollutants originating from the Layari and Malir rivers. In 2015, Petrova and Gerdzhikov conducted research on the dynamics of phytoplankton taxonomic makeup in the coastal waters of Bulgaria (2008–2010). 204 species and types of microalgae were found in the 389 samples that were studied in total, spread among 14 classes. Dinophyceae (40.20%) and Bacillariophyceae (31.86%) made up the greatest portion. The remaining 27.94% contained a variety of microalgae. Peridineas and diatoms alternated dominance throughout the hydro-biological seasons, displaying a well-defined cyclic recurrence. Throughout the study period, June and September saw the maximum species diversity whereas April, July, and December saw the lowest species composition.

Achary et al. (2014) reported on the nutrient dynamics and seasonal variation of phytoplankton assemblages in the coastal waters of the southwest Bay of Bengal. In the near shore seas of Kalpakkam, on the east coast of India, observations were undertaken during 2008 and 2009 to understand the phytoplankton community structure and its relationship to environmental variables. There were 219 species of phytoplankton in the population, and compared to the north east monsoon (NEM) season, the density was higher during the southwest monsoon (SWM) and inter-monsoon seasons. On a temporal and spatial scale, the nutritional status revealed the influence of point sources conveying anthropogenic runoff. The Redfield ratio (N/P/Si = 16:1:16) and ambient nutrient ratios' comparisons revealed a distinct temporal change in the parameters that control phytoplankton development. While P-limitation prevailed during the NEM season (75%), acute N-limitation of algal development was evident during the SWM and inter-monsoon season (76%). It's important to note that a sizable colony of cyanobacteria (*Trichodesmium erythraeum*) was observed during the NEM season, when there was an exponential spike in nitrogen concentration, likely due to nitrogen fixation. Temperature had no observable impact on phytoplankton proliferation in situ during the study period.

New records of maritime pennate diatoms were worked by Park et al. (2014) in Korea. 49 sites in Korea's marine and brackish plankton and benthic ecosystem were used for a study on native diatoms from November 2008 to December 2012. Both scanning electron and light microscopy were used to examine the structure of small pennate diatoms. Twenty new species of diatoms were found in this inquiry, which resulted in their classification into five orders, 18 families, and nine genera. The nomenclature, references, specimens examined, specimen descriptions, pictures, and distribution profiles are all included in this study. We provide a technique to comprehend the diversity of diatoms in Korea in light of the recently revealed pennate diatoms, which suggest numerous explanations for why these species have not been previously identified in Korea.

In Bhavanapadu Creek, Srikakulam District, South India, Amarnath et al. (2013) conducted research on the distribution and variety of phytoplankton in relation to hydrography. From December 2009 through November 2010, five separate stations conducted monthly samplings. 39 species are included in the four classes of phytoplankton, which are distributed as follows: Bacillariophyceae (97-91%), Pyrrophyceae (0-4%), Chlorophyceae (0-4%) and Cyanophyceae (1-8%). The hydrographical characteristics affect the phytoplankton population density and diversity, and they have a significant (P0.05) inverse relationship with factors including temperature, salinity, and dissolved oxygen. 0 to 0.602 was the Shannon Weiner index (H).

Researched by Moharana & Patra, (2013) at Digha Sea Shore of the Bay of Bengal, seasonal fluctuations in phytoplankton and zooplankton dynamics were observed both statistically and subjectively. There were found to be a total of 72 species of Phytoplankton, with 23 species (or 31.94%) belonging to the Chlorophyta phylum, 14 species (or 19.4%) to the Bacillariophyta phylum, and 8 species (or 11.1%) to the Cyanophyta phylum. In terms of changes in zooplankton species, the dominant taxa are Protozoa (38.70%), Rotifera (25.80%), Cladocera (22.58%), and Copepoda (12.90%), which encompass 12, 8, 6, and 4 species, respectively. The biggest numbers were contributed by Cladocera in zooplankton and Chlorophyta in phytoplankton.

The effects of climate change on the phytoplankton bloom (Prymnesiophyceae: *Phaeocystis spp*.) in the North Andaman coastal region were researched by Sachithanandam et al. (2013) . In the Andaman Sea, there was a phytoplankton bloom in June 2011 before the monsoon season. The four forms of bloom that have been identified so far are Phaeocystales, Cyanophyceae (Cyanobacteria or Blue-green Algae), Dinophyceae (Dinoflagellate), and

Bacillariophyceae (Diatom). The *Phaeocystis* species were observed using the following seawater physicochemical characteristics between the surface and 15 m deep. The potential influence of human activities on the occurrence of *Phaeocystis spp*. in this region includes eutrophication resulting from water discharge, elevated nitrogen levels in the water column, as well as impacts from precipitation, upwelling, and wind stress. Phytoplankton blooms in the coastal waters of the north Andaman areas may be caused by physicochemical parameters that are triggered by climatic variations. *Phaeocystis* has not yet been seen blooming anywhere along the Indian coastline, according to an assessment of algal blooms off the country.

Aziz et al. (2012) looked at the diversity, abundance, and density of estuarine phytoplankton from nine sites throughout four Sundarban Mangrove Forests (SMF) regions in Bangladesh. 36 species from the families Chlorophyceae, Euglenophyceae, Bacillariophyceae, and Xanthophyceae made up the phytoplankton communities. Near the Hangsha River (R) and River Murdat confluence in Patcosta, taxonomic distribution and densities were highest. The highest Shannon-Wiener diversity index (H = 3.494) was also found in this region. In Bal R., Bisandri Khal, and Kalabogi R., the lowest phytoplankton density and diversity indices (H = 1.661) were discovered. High and low tides were present in all nine places where *Coscinodiscus lineatus* was discovered, illustrating its exceptional adaptability to environmental changes. Only the Passur River, which has low salinity, conductivity, and total dissolved solids, was home to *Chaetoceros socialis*. When the tide was low compared to high, there were often more phytoplankton individuals per liter. The results of Principal Component Analysis (PCA) revealed a connection between some phytoplankton species and pH.

Karthik et al. (2012) investigated the variety and distribution of phytoplankton in the southern Andaman Sea's coastal waters between September 2011 and March 2012. In this investigation, a total of 227 species from 67 genera were identified. Diatoms contributed more to the overall abundance (68%) than Cyanophyceae (24%) or Dinoflagellates (8%), in that order. The percentage of silicoflagellates was lower (0.4%). 164 species of diatoms from 46 genera were represented, as were 58 species of dinoflagellates from 16 genera, and 2 genera each of cyanophyceae and silicoflagellates. The density of phytoplankton exhibited a range of 0.4 × 10^5 to 4.2 × 10^5 cells per liter. In September, December, and March, St. 2 exhibited elevated population densities and chlorophyll a level due to the cyclical proliferation of diatom species such as *Coscinodiscus centralis* (95000 cells ml-1), *Rhizosolenia imbricata* (19000 cells ml/l), and *R. alata* (9500 cells ml/l). In St. 4, it was observed that locations characterized by lower levels of anthropogenic activity, such as Carbyn's Cove, had comparatively higher levels of species diversity (H=3.6) and equity in plankton flora (J=0.9), as evidenced by a biochemical oxygen demand (BOD) measurement of 2.7 mg/L. A virtually monospecific colony of the red tide species *Trichodesmium erythraeaeum* (27000 cells ml/l) at St. 3 in March was discovered during the current investigation. At Puri Sea Shore of the Bay of Bengal, seasonal fluctuations of phytoplankton dynamics were observed, according to Mohapatra & Patra, (2012), both statistically and qualitatively. There were 45 species of Chlorophyta (53.60%), 17 species of Bacillariophyta (29.45%), and 12 species of Cyanophyta (16.75%) identified in the phytoplankton as a whole. Due to the presence of photosynthetic pigments that convert solar energy into molecular sugars that are then consumed by consumers, or heterotrophs, phytoplankton are producers or photosynthetic organisms. They are therefore essential to the marine ecology.

Sridhar et al. (2010) documented the spatial and temporal variations in phytoplankton in coral reef and seagrass habitats in Palk Bay, on the southeast coast of India. The Palk Bay coral reef and seagrass ecosystem's regional and temporal phytoplankton dispersion features were studied between April 2002 and March 2003. During the study period, 133 species of phytoplankton were identified, of which 98 species are members of the Bacillariophyceae family, 15 species are Dinophyceae, 12 species are Cyanophyceae, and 8 species are Chlorophyceae. Diatoms (57.14–94.10 percent) dominated the percentage composition of the different phytoplankton groups at the two sites, followed by dinoflagellates (3.12–28.57 percent), blue-greens (2.43–12.5%), and greens (3.7–7.69 percent). At both sites, the phytoplankton population density increased during the summer (St.1. 62,000 cells/l and St.2. 55,000 cells/l). The productivity of the seagrass ecosystem was about half as great (2.10-130.21 mg C m-3 hr-1) as that of the coral reef habitat (3.30 - 85.56 mg C m-3 hr-1). At station 1, there was a higher concentration of chlorophyll-a, which is consistent with the higher phytoplankton population density and primary productivity seen there.

Boonyapiwat et al. (2008), examined the species composition, quantity, and distribution of phytoplankton in the Bay of Bengal. The Bay of Bengal's species composition, abundance, and distribution of phytoplankton were examined in November 2007 using water samples taken at the surface layer of 24 sites in the north, west, and east. A total of 135 phytoplankton species were identified, including 2 cyanobacterial species, 78 diatom species, 53 dinoflagellate species, and 1 silicoflagellate species. Each area's species distribution was noted. The two dominating species in every location were *Oscillatoria erythraea* and *Proboscia alata*. High densities of *Pseudonitzschia pseudodelicatissima* appeared, creating blooms in the Northern Bay. The greatest concentration of phytoplankton was 133,790 cells/L. During this survey, dinoflagellates did not predominate the phytoplankton population.

At five stations across the Andaman Islands in October 1996, the vertical distribution of phytoplankton in the upper 200 m of the water column was examined, according to Sarojini & Sarma, (2001). There are 143 species of algae known, categorized into 8 classes. The majority of the biomass was given by Cyanophyta, particularly *Trichodesmium erythreae*, whereas Bacillariophyceae and Pyrrophyceae had the highest species diversity. In the seas on the Bay of Bengal side, dense maxima were found at around 25 meters of depth, and less dense maxima were found near the surface. Pyrrophyceae reached their depth maximum up to 50 m, and Bacillariophyceae did the same between 25 and 75 m. For certain species, a vertical stratification was also seen. The waters of the Andaman Sea and the Bay of Bengal have different hydrographic characteristics. In the former, in addition to biotic factors, differences in the distribution of phytoplankton on the two sides off the islands are linked to a tongue of warmer, more saline water that is present at depths of 25–150 m and is coming from the Arabian Sea.

In two estuaries with a predominance of mangroves, Saifullah et al. (2016) examined the composition and diversity of phytoplankton with physic-chemical parameters. Salinity and conductivity, as well as ammonium and phosphate, were shown to influence the abundance of Bacillariophyceae and Dinoflagellates in KS, whereas temperature, total dissolve solid, dissolve oxygen, and pH were found to influence the abundance of Chlorophyceae. The effects of salinity, conductivity, and PO_4, NH_4 on the abundance of Dinoflagellates, Chlorophyceae and Bacillariophyceae, were also observed.

The study undertaken by Akter et al. (2015) aimed to investigate the composition and abundance of phytoplankton in fish ponds located in two fish farms within the Noakhali area. The inquiry involved the measurement of various water quality indices, namely salinity, temperature, clarity, and dissolved oxygen. The pH, conductivity, and productivity of phytoplankton were all measured. There are 21 genera in the Bacillariophyceae, Chlorophyceae, Cyanophyceae, and Euglenophyceae families of phytoplankton. *Euglena, Microcystis,* and *Eurolena* were the most common genera found.

Ghosh et al. (2012) found the diversity and seasonal variation of phytoplankton. Canonical Correspondence Analysis was used to establish a correlation between several physico-chemical parameters and phytoplankton density. The density of phytoplankton grew as warmth and nutrients increased, according to this study. When compared to the pre-and post-monsoon periods, bioindication during the monsoon period showed a low diversity species community with better water quality. The Shannon-Wiener diversity index was very effective at determining the trophic condition of the water as well as the status of pollution, which in this case suggested that this lake had a moderate amount of pollution.

In their study, Sharif et al. (2007) examined the primary flow patterns within the river systems of Bangladesh, tracing their trajectory from the northern regions to their ultimate discharge into the Bay of Bengal. Pre-monsoon, monsoon, and post-monsoon phytoplankton occurrence and distribution studies were conducted in the lower Meghna throughout the pre-monsoon, monsoon, and post-monsoon seasons. A total of 61 phytoplankton genera were discovered over the course of the yearly cycle. During the pre-monsoon season, diversity was highest, and during the monsoon season, it was lowest. The diversity of phytoplankton was higher in the upper estuary and lower in the mouth.

Rahaman et al. (2013) investigated the regional and temporal fluctuations in phytoplankton abundance and species diversity within the mangrove forest of the Sundarbans in Bangladesh. The taxonomic composition, quantity, and geographic distribution of phytoplankton, together with the water quality, were examined by the researchers in three prominent river systems within the Sundarbans. There were 134 phytoplankton species identified, with diversity and abundance fluctuating throughout time and space. Seasonal variations in chlorophyll-a concentrations ranged from 0.24 to 5.94 µg/L, with the maximum phytoplankton biomass seen in Bhola-Baleswar during the summer. Transparency, salinity, and nutrients were all found to be positively associated to chlorophyll concentration.

Tan et al. (2016) examined Singapore's marine phytoplankton as well as harmful micro algae in the region. Between May and June 2013, a survey of marine phytoplankton in the Singapore Strait was conducted to determine the variety of phytoplankton in Singapore's coastal waters. Using a 20 m-mesh plankton net, 34 different microalgal samples were taken from coastal sediments. Samples were stored in Lugol's solution under the microscope and as closely as possible identified to species. With 49 new reports from the Singapore seas, the list of marine micro-phytoplankton has been revised to contain 270 taxa.

In order to evaluate the water quality and bio-ecoaesthetic value of the area, Tan et al. (2016) reported phytoplankton, zooplankton, and zoobenthos at 8 sample stations across the coastline area of the Bay of Bengal during the summer season. Bacillariophyceae was the dominant group of taxonomic categories in terms of phytoplankton species. According to research on zooplankton, it appeared that Cladocera (*Daphnia sp., Allonella sp.,* and *Moina sp.*) and Rotifera (*Brachionus sp. and Keratella sp.*) are the most common in the area, followed by Copepoda (*Cyclops sp.; Naupliuslarva*) and Ptotozoa (*Acanthoc Foraminifera* (11 species), Ophiuroides (7 species), Ostracoda (3 species), and Polychaeta dominated the zoobenthos (1 sp.). For phytoplankton, zooplankton, and zoobenthos, average counts were calculated as 165/ml, 1825/m3, and 17750/m2, respectively. In the research area of the Bay of Bengal at Nellure, higher diversity indices for all these types of phytoplankton, zooplankton, and zoobenthos were between 2.615 and 2.072 and 2.18, respectively, showing the least or no impact of pollution or any negative impact (Andhra Pradesh, India).

The study conducted by Iqbal et al. (2014) investigated the impact of seasonal environmental factors on the variability of zooplankton in the rezu khal estuary located in Cox's Bazar, Bangladesh. Throughout all three seasons, copepods were found to be the predominant species within the zooplankton community. Specifically, copepods accounted for the largest proportion, reaching a peak of 65.77 percent during the winter season and a minimum of 34.09 percent during the pre-monsoon season. The abundance of the most abundant zooplankton group was observed to be negatively affected by salinity and total dissolved solids. The larval stages of Chaetognatha and mollusks exhibited a favorable response to variations in water pH.

The study undertaken by Srichandan et al. (2015) centered on the spatial distribution of zooplankton in the coastal area of the northern Bay of Bengal. In the course of this investigation, a total of 186 species of holoplankton and 23 distinct types of meroplankton were successfully discovered. The zooplankton assemblage was predominantly comprised of 112 copepod species, which are taxonomically classified into four orders and 26 families. The Calanoida, which is the most prevalent order of copepods, originated. The results also indicated that while the monsoon season exhibited the greatest diversity of species, the pre-monsoon season exhibited the largest abundance of species.

In oceans, zooplankton essentially consumes phytoplankton, which then uses its energy to pass it up the food chain to a number of higher creatures. These organisms can move or cannot move, and they exhibit vertical mobility while adhering to seasonal and tidal cycles to ascertain their horizontal positions within the water (Thurman & Burton, 1997). Copepods make up the majority of zooplankton in terms of biomass, and their rate of feeding rises as phytoplankton abundance rises until a saturation density is reached (Speight & Henderson, 2007). Copepods aren't the only zooplankton that feed on phytoplankton; crustacean nauplii, euphausiids, and ciliate protozoa are further examples. In the context of the pelagic grazing food chain in marine ecosystems, it is noteworthy that zooplankton holds considerable importance alongside phytoplankton. Due to the functional characteristics of its biotic components, zooplankton is of highest importance in aquatic ecosystems. The concepts encompassed in this category consist of food chains, trophic networks, energy transfer, and matter cycling.

A. Islam & Aziz, (1975) researched the zooplankton in Bangladesh's northeastern BoB, where they had previously identified 18 species. But the BoB has a far higher species composition of zooplankton. Based on the studies conducted by Fernandes & Ramaiah, 2009, Sahu et al., 2010, Baliarsingh et al., 2015, and Srichandan et al., 2015, the collective findings indicate the presence of 163, 93, 239, and 209 distinct species of zooplankton, respectively. The investigations carried out in various areas of the Indian BoB make this clear. Therefore, less research has been done on the faunistic composition of the zooplankton in the Bangladeshi portion of BoB than on that in the Indian portion. The floristic and faunistic composition of plankton of the BoB in Bangladesh must be completed urgently in light of the "Blue Economy" theory, which is based in part on the investigation of biological production.

In the study conducted by Bhattacharya et al. (2014), an investigation was carried out on the structure of the meso-zooplankton community in the coastal waters of the Sundarbans mangrove. The researchers identified salinity, chlorophyll-a levels, and transparency as potential hydrological parameters that may influence the distribution and abundance of the dominating copepods and total chaetognaths in this ecosystem. The estuary's mouth exhibited a significant correlation between a high diversity index (3.21), indicating a wide range of species present, and high richness indexes (4.39), indicating a large number of species, as well as high evenness indices (0.96), indicating a relatively equal distribution of individuals among the different species. The findings of the study indicate that the calanoid copepod *Bestiolinasimilis* exhibited exclusive dominance throughout all of the surveyed sites. The *Chaetognath* species, *Sagitta bedoti*, has a persistent dispersion pattern, wherein the juvenile form (also referred to as stage I) holds significant importance.

The zooplankton assemblages in neritic and marine environments were studied by Rakhesh et al. (2006). A total of 112 taxa were found in the Bay of Bengal, which is located off the northeast coast of India. The majority of the population (87% to be exact) was made up of copepods (58 different species). The study suggests a link between salinity and differences in the composition of zooplankton communities in different bodies of water. Low salinity (26.9 to 28.9 parts per thousand) in coastal waters is favorable for the growth of a variety of zooplankton, including *Acrocalanus sp., Corycaeusdana sp., Oikoleura sp., Acartia sp., Evadnetergestina sp.,* and *Creseis sp.* Fernandes & Ramaiah, (2009) observed geographic variation in the Mesozooplankton population in the Bay of Bengal (India) throughout the summer monsoon. Out of the total number of observed species, specifically 163, a significant majority of 132 species were classified under the prominent order of Copepods known as Calanoida. Based on the results of their study, it was determined that the mesozooplankton biomass, copepod species richness, and diversity were comparatively higher in the central Bay as opposed to the western Bay. Despite the fact that eddy stations exhibited greater zooplankton biomass and density, no statistically significant correlation was seen between zooplankton and chl-a. The grazer meso-zooplankton demonstrates an early utilization of the enhanced phytoplankton productivity within cold-core eddies.

2.4 Distribution of Nutrients in Seawater

Due to their participation in several functional biochemical processes, nutrients in ocean water are essential for biological productivity, management of aquatic ecosystems, and the existence of living things (Asanuma et al., 2014; Sun et al., 2022; Yang et al., 2018; M. Zhong et al., 2018; P. Zhong et al., 2017). From phytoplankton to zooplankton, which are the principal food providers, nutrients play a part. In order to produce amino acids, proteins, and related compounds that are eventually devoured by creatures higher up the food chain, phytoplankton mostly use nutrients. But living things only need a very little amount of these nutrients. The ecological components are concerned when there is an excessive concentration of nutrients in the ocean water because it reduces biological productivity and affects biogeochemical processes, which causes eutrophication or nutrient enrichment of the coastal waters (Asanuma et al., 2014; Chen et al., 2012; Glibert et al., 2010; Yang et al., 2018; P. Zhong et al., 2017). Numerous manifestations are brought on by eutrophication or nutrient enrichment, including cyanobacterial blooms, jellyfish blooms, hypoxia, and ocean acidification. During the inter-monsoon and southwest monsoon seasons, tropical cyclones like this are common in the Bay of Bengal and lead to catastrophic events like phytoplankton blooms (Gomes et al., 2000; Sarma et al., 2013; Vinayachandran, 2009).

It is evident to follow the source of nutrients and to take the necessary precautions in order to verify the nutrient enrichment in ocean water. For both natural and manmade reasons, the concentration of nutrients may increase. Land and sea collide in coastal or island areas, which naturally results in nutrient enrichment. Furthermore, due to seasonal change, significant river flow from the Meghna, Matamuhuri, Bakkhali, and Naf, and proximity to other runoffs from the Myanmar region, the North-eastern Bay of Bengal is a sophisticated and varied region (Patra et al., 2007). The region is also affected by variations in the monsoon throughout the year, which are characterized by significant precipitation (Sarma et al., 2013; Varkey et al., 1996), a decreased rate of evaporation, a variety of wind patterns, and tidal circulation. As a result, it has been shown that nutrient inflow and accumulation are distributed abruptly (Sarma et al., 2013). Numerous sources are involved in increasing the nutrient concentration in ocean water and sediment when anthropogenic sources are taken into account. Increased nutrient concentration in water, excessive fertilizer and pesticide usage for irrigation, the mixing of water-based vehicle waste with ocean water, and rapid urbanization are all contributory factors (Mbaye et al., 2016; Sun et al., 2022). Consequently, it is essential to evaluate nutrient distribution, variations in nutrient concentration, composition, and source identification in order to use them as a theoretical and numerical framework for creating the necessary strategies for the preservation of ecological balance and ecosystem resilience.

Systematic research was conducted on St. Martin's Island, the Bay of Bengal's most diverse ecosystem and sole coral-bearing island, taking into account the ecological significance of nutrients. This island has a remarkable degree of biodiversity, boasting a total of 300 molluscan species, 150 fish species, 5 amphibian species, 66 coral varieties, 5 snail species, 200 avian species, 5 turtle species, and 20 mammalian species. (M. Ahmed, 1995). The ecosystem of the islands includes soft coral habitats, sandy and rocky intertidal habitats, rocky subtidal habitats, a variety of flora and animals, and soft-bottom offshore habitats (M. Z. Islam, 2002; Thompson & Islam, 2010). Studies on the origin, spatial distribution, and pace of nutrient buildup with respect to temporal variation have grown in importance as study topics in coastal and estuarine ecosystems due to their relevance.

Prior to now, the majority of study has focused on temporal and spatial variance across the globe (Sun et al., 2022; Wang et al., 2012; Yang et al., 2020). Numerous researches on some ecological catastrophes, such as hypoxia, eutrophication, and algae blooms, were conducted. Prasanna Kumar et al. (2004) discovered the cold-core ripples as significant nutrient sources that support phytoplankton blooms in the Bay of Bengal while researching the source. Due to nutritional variance in various habitats, the most explicit research has been done on phytoplankton distribution, abundance, and diversity. The seasonal occurrence of suboxic or hypoxic conditions along the west coast of India through river runoff that is close to the Bay of Bengal was first identified by Naqvi et al. (2000) as being caused by coastal upwelling and human-induced factors during the current time (Sarma et al., 2013). Additionally, Recent research has revealed that the process of nutrient enrichment can lead to significant alterations in nutrient stoichiometry, hence influencing the diversity and composition of phytoplankton communities (Achary et al., 2014; Justić et al., 1995; Piehler et al., 2004). In-depth investigations on nutrient dynamics (Achary et al., 2014) and geochemical cycling of nutrients (Sarma et al., 2013) are also being conducted in the Bay of Bengal. In the year 2020, a study conducted by Xin Meng and colleagues examined the vertical distribution characteristics of nitrogen (N) and phosphorus (P) in both the overlaying water and pore water. The fluxes of ammonia (NH_4+-N) and phosphate were determined through the utilization of a one-dimensional transport-reaction model, which relied on Fick's First Law (PO_4^3-P). The findings indicated that the water situated above Liangzi Lake exhibited average concentrations of NH_4+-N and NO_3-N at 2.59 and 0.46 mg L1, respectively. The average amounts of PO_4^3-P were found to be below the detectable threshold. The maximum concentrations of both N and P were found near the sediment-water contact. For instance, the top 5 cm of the surface layer's pore water had an average ammonia content of 4.29 2.74 mg/L1, which was twice as high as the water above it. There were found to be two distinct regimes of the PO_4^3-P vertical profile, one with a trend toward progressive increase and the other with an increase followed by a decline. In the surface layer (0–5 cm) pore water, the mean orthophosphate content was 0.01–0.01 mg/L. Ammonia flux levels were distributed spatially in a highly diverse manner.

The presence of nitrate and nitrite in the photic zone was found to be generally imperceptible during the majority of the year, as evidenced by the activity of phytoplankton (Nahimana et al., 2008). However, it was discovered that ammonium levels were unusually high and that silicate concentrations were at their lowest. The occurrence of elevated amounts of nitrate and nitrite is frequently found at depths ranging from 30 to 70 meters, attributed to nitrification processes. Conversely, ammonium tends to concentrate in the deeper regions of the water column when oxygen is depleted. Silicates were observed to proliferate from the photic zone down to the ocean floor due to the process of biogenic silica dissolution.

The study conducted by Perassoli et al. (2020) investigated various water masses, including coastal water (CW), tropical water (TW), South Atlantic central water (SACW), Antarctic intermediate water (AAIW), and upper circumpolar deep water (UCDW). An extended optimal multiparameter study was conducted in order to spatially represent the distribution of nutrients. This analysis utilized a combination of nonconservative features, including dissolved oxygen (O_2), nitrate (NO_3), silicate (SiO_2), and phosphate (PO_4^3), along with conservative parameters such as temperature and salinity. The hydrodynamics of this region, including continental outflow, the Brazil Current, and local variability, exert significant influence on the presence and spatial distribution of water masses. The distribution of nutrient concentrations was found to be highly impacted by various factors, including the distribution of water masses, activities associated to nutrient regeneration, coastal upwelling, erosion of the upper thermocline, and the occurrence of cyclonic eddies. Consequently, within the continental shelf region, the segments of the water column that were occupied by Cold Water (CW) and Transitional Water (TW) had the most elevated levels of SiO2 and dissolved oxygen. Conversely, Sub-Arctic Central Water (SACW) displayed the greatest quantities of NO_3. The nutrient contents of the intermediate water masses located offshore were found to be the greatest (SiO_2, NO_3, and PO_4^3) (AAIW and UCDW). Furthermore, due to interactions and creation processes between the ocean and atmosphere, the largest quantities of dissolved oxygen were found around TW and AAIW.

Nutrients are necessary for the growth of phytoplankton, which is an essential component of the marine food web (Meirinawati & Fitriya, 2018). In relation to primary productivity, the concentration of nutrients in the water affects fisheries stocks. The deep-sea nutrients have so far only sporadically been the subject of research in Indonesia. This research aims to evaluate the water quality and the horizontal and vertical distribution of nutrients in eastern Indonesian waters in order to establish a baseline for deep-sea nutrient levels in Indonesia. Nutrient measurements were conducted in accordance with Strickland and Parsons' recommendations (1972). The study found that the concentrations of phosphate, nitrate, nitrite, ammonium, and silicate ranged from 0.000 to 0.060 mg/l, 0.001-0.321 mg/l, 0.000 to 0.009 mg/l, 0.004-0.024 mg/l, and 0.085 to 1.090 mg/l, respectively. The concentration of nutrients was often higher in the Maluku Sea. The vertical distribution of nitrate, phosphate, and silicate shows that concentrations increase with depth, with the exception of nitrite and ammonium. The distribution of ammonium is uniform, although the northern region has the highest concentration of nitrite.

Seetharam et al. (2014) examined how nutrients (ammonium, nitrite, nitrate, phosphate, and silicate) were distributed in the Bay of Bengal's coastal waters. Significant differences were found for practically all identified nutrients. Ammonium, nitrite, nitrate, phosphate, and silicate each had detectable ranges of 0.026-23.52, 0.018-0.41, 0.026-4.46, 0.18-7, and 0.37-20.31 M. The silicate nutrient species outperformed the other four of the five investigated. Regarding nutrient concentration, there were significant discrepancies between the surface and bottom. In this study location, nutrient concentrations varied due to increased water mixing brought on by enhanced wind and wave interaction.

2.5 Distribution of Heavy Metals in the Seawater

Hong et al. (2022) analyses of the geographical and temporal fluctuations of nutrients, heavy metals, water quality, and pollution sources in surface water was published. With the exception of lead (Pb), all 12 pollutants showed substantial seasonal fluctuations, while the differences were quite modest. Geographically, nutritional elements were significantly concentrated in central and northern Tibet's pastoral and agricultural development areas. The majority of Tibet's waterways were deemed to be of good quality overall, and 41 monitoring sections had water that met the Class I water criterion according to the entropy method-fuzzy evaluation approach. The origins of the pollution components were examined using a multivariate statistical method in the study. Four major components were found using the principal component analysis approach. The findings of this study can serve as a scientific foundation for water ecology research and pollution prevention and management.

In their study, Waseem et al. (2014) conducted an investigation into the presence of heavy metal pollution in various places across Pakistan. The primary objective of their research was to assess the extent of heavy metal contamination in water sources over a specific time period. The mentioned contaminations have significant implications for water quality, ecological environment, and the food chain. Furthermore, the presence of contaminants in water, soil, and agricultural products presents a significant risk to human well-being.

In their study, Gupta & Abu-Ghannam, (2011) conducted an assessment of the potential health risks linked to the consumption of fish sourced from the Gomti River in India. The fish samples were found to be polluted with various heavy metals, including Cr, Cu, Mn, Ni, Pb, and Zn. The health risks were evaluated using target hazard quotients (THQs). The concentrations of various metals (Cr, Cu, Mn, Ni, Pb, and Zn) in the muscle tissues of eight fish species (*Mastacembelus puncalus, Clupisoma garua, Cyprinus carpio, Botia lochachata, Channa punctatus, Heteropneustis fossilis, Puntius sophore, and Clarias batrachus)* exhibited a range of values. Specifically, the concentration ranges were as follows: Cr (2.2-2.14), Cu (0.3-14.3), Mn (2.3-5.5), Ni (0.5-10.9), Pb (1.0-3.9), and Zn (12.3-46.9). The elements Zn, Cr, Ni, Mn, Cu, and Pb exhibited a sequential pattern of accumulation in fish muscle tissue.

In their study, Hu et al. (2013) employed inductively coupled plasma mass spectrometry (ICP-MS) to evaluate the spatial distribution and ecological risk associated with chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) in surface sediments collected from the coastal region of the Yellow Sea, specifically the Shandong Peninsula. The assessment of the increased concentration of Pb in the region is conducted by the utilization of the enrichment factor (EF) and geo-accumulation index (Igeo). According to the spatial distribution of the ecotoxicological index, 21% of the surface sediments are likely to be toxic. By using the pollutant load index (PLI), similar outcomes were also attained. The spatial distribution pattern of heavy metals in surface sediments serves as a foundation for actions necessary to safeguard the quality of marine sediment.

Due to heavy metal contamination brought on by growing urbanization and industrialization, south China's coastal regions confront significant difficulties (Wang et al., 2012). The findings demonstrate a strong correlation between heavy metal levels and regional economic growth. Heavy metal contamination in the Pearl River Estuary and Hong Kong was very bad. Heavy metal concentrations were, however, discovered in the biota from Ling-dingyang in the Guangdong province. In comparison to other species, mollusks showed higher levels of heavy metals. Assessments of the risks to human health indicated that some seafood from South China's coastal regions contained levels of heavy metals over the recommended limits.

Zhao et al. (2012) studied the danger of sedimentary metals in the Yangtze Estuary, including As, Cu, Mn, Pb, Sb, and Zn. New information about the connections between two common indexing techniques Each sampling site's ecological risk was uniformly low to moderate in intensity. According to the speciation index that was utilized, the contamination levels of these locations were low to moderate, however the total content indices suggested a moderate to substantial contamination. When evaluating the dangers of Cu, Pb, and Zn, there was a strong positive association between the two index approaches; however, there were discrepancies and negative correlations for As, Mn, and Sb. Three metal factors-the fractional distribution, the degree of enrichment, and the hazardous reaction factors were primarily responsible for the correlated behaviors.

Vicente-Martorell et al. (2009) conducted an assessment of the bioavailability of heavy metals in the water, sediments, and fish species in the estuary of the Tinto and Odiel rivers in Huelva, Spain. In addition to observing elevated concentrations of total and dissolved zinc (Zn) and copper (Cu) in the aquatic environment, significant contamination levels of zinc (Zn), lead (Pb), arsenic (As), and copper (Cu) were detected in the sediment samples. Significant amounts of copper (Cu) and zinc (Zn) were detected in the liver tissue of *Sparus aurata* and *S. senegalensis*.

Hasan et al. (2013) investigated the contamination of groundwater and saltwater with trace metals in the Bangladeshi port city of Chittagong's shipbreaking district, Sitakunda Upazilla. This study identifies the Sitakunda Upazilla, Chittagong, Bangladesh shipbreaking operations as probable sources of trace metal accumulation in the groundwater and ocean. The shipbreaking operations are located along the Bay of Bengal. When compared to WHO and local requirements for water quality in Bangladesh, it was discovered that seawater was significantly contaminated by Fe and Hg, marginally by Mn and Al, and scarcely by Pb and Cd. Fe, Pb, and Hg were the most heavily polluting elements in the groundwater, followed by Mn, Al, and As. All seawater samples had trace element concentrations that were higher than the typical seawater elemental concentration. Principal Components Analysis was used to identify two pollutant sources: marine and shipbreaking. The mechanism of groundwater contamination states that if seawater is contaminated, seawater intrusion may cause nearby groundwater to become contaminated with trace metals as well.

Tekin-Özan, (2008) discovered several heavy metals (Cu, Fe, Zn, and Mn) in the Beysehir Lake, an important location for bird mating and travel as well as a source of water for irrigation and drinking. These metals were found in the water, sediment, and various tissues of the fish *Tinca tinca*. Of the metals under study, Fe is present in the water at the greatest levels. In general, metal concentrations rose during the hottest time of year and fell throughout warm seasons. Results for levels in water were compared to published literature data for the lakes as well as national and international water quality criteria. Fe concentrations in sediment samples were the greatest; similarly, springtime concentrations of Cu and Zn were higher than those of Fe and Mn. Cu and Mn, two of the heavy metals investigated, were below the detection threshold in several tissues. In comparison to the fall and spring seasons, larger concentrations of the tested metals were often reported in the summer and winter. *T. tinca's* liver contained high concentrations of heavy metals, but muscle samples contained modest concentrations. The quantities of metals found in the analyzed fish's muscle were safe for eating by humans. The current study demonstrates the necessity for safety measures to stop the spread of heavy metal pollution.

Sharif et al. (2007) conducted a study to examine the presence of trace metals in tropical marine fish collected from the Bay of Bengal. The flesh of six marine fish species from the Bay of Bengal was analyzed to determine the concentrations of calcium, potassium, magnesium, manganese, copper, iron, nickel, zinc, lead, cadmium, strontium, and rubidium. The analytical quality was evaluated by conducting an analysis of the International Atomic Energy Agency's standard reference material MA-A-2 (TM), namely the fish flesh homogenate. In most instances, the results align with existing data on fish derived from various maritime ecosystems.

The distribution of the four heavy metals (Cr, As, Cd, and Pb) in the surface water of the Meghna River estuary and the seasonal variation of several physicochemical parameters were illustrated by Safiur Rahman et al. (2021). Additionally, the study assessed the potential health hazards posed to both adults and children when they are exposed to surface water in close proximity, considering the risks associated with both ingestion and skin absorption. The research area exhibited varying levels of metal content, specifically arsenic (As), cadmium (Cd), lead (Pb), and chromium (Cr). The ranges of metal concentration observed were as follows: As (0.012-0.036; mean 0.024 ± 0.007), Cd (0.009-0.050; mean 0.018 ± 0.012), Pb (0.007-0.014; mean 0.009 ± 0.007), and Cr (0.036-0.054; mean 0.045 ± 0.005). Typically, the As, Cr, Pb, and Cd concentrations were higher than those advised for human consumption. Consequently, it is anticipated that the presence of metal pollution in the research area can be attributed to a combination of natural and anthropogenic influences.

2.6 Prospect of Blue Economy

The emergence of the Blue Economy notion can be attributed to the increased focus of nations on harnessing their maritime resources. The utilization of water and marine resources at national and international levels has presented novel opportunities for economic development in coastal countries. The aforementioned concept has evolved into a call to action for the promotion of sustainable development. Given that marine resources serve as the only raw materials for the blue economy, it is imperative for each nation to assume its fair share of duty in safeguarding the seas. These bodies of water include around 64 percent of the Earth's oceanic surface and account for over 90 percent of the overall expanse (Snelgrove et al., 2016).

The concept of the Blue Economy, stemming from Gunter Pauli's book titled 'The Blue Economy: 10 years, 100 innovations, 100 million jobs' (Pauli, 2010) entails the amalgamation of Ocean Economy advancements with the concepts of social inclusivity, environmental sustainability, and new, dynamic business strategies. The concept of the Blue Economy encompasses the responsible utilization of marine resources to foster economic development, enhance quality of life, generate employment opportunities, and promote the well-being of oceanic ecosystems.

According to the Blue Economy Concept Paper (2012), it has been observed that the Earth's oceans encompass around 72% of the planet's total surface area, making them a significant component of the global ecosystem, accounting for over 95% of the biosphere. The beginning of life may be traced back to the seas, which currently play a crucial role in sustaining all forms of life. They accomplish this by facilitating the production of oxygen, the absorption of carbon dioxide, the recycling of nutrients, and the regulation of global climate and temperature. Oceans have a significant role in supporting a substantial amount of the global population by providing food and livelihoods, as well as serving as a crucial medium for the transportation of goods in global trade (Blue Economy Concept Paper, 2012). The marine and coastal environment serves as a significant resource for the worldwide tourism sector, playing a crucial role in many stages of tourism development, ranging from infrastructure to the popular "sun, sand, and sea" concept, as well as the growing field of nature-based tourism. The study elucidates that the seabed presently contributes to 32% of the worldwide hydrocarbon supply, and there is an ongoing expansion in exploration activities in this domain.

In a study conducted by Creel, (2003), an explanation is provided regarding the demographic relationship with the ocean. According to the researcher, it has been observed that coastal regions, which accommodate a significant and expanding share of the global population, are experiencing a deterioration in their environmental conditions. The issue is especially pronounced in emerging nations. Presently, an estimated three billion individuals, including around fifty percent of the global populace, reside in close proximity, specifically within a distance of 200 kilometers, to coastal areas. According to the findings of this study, it is projected that the aforementioned figure will experience a substantial increase by the year 2025. The dense population in coastal areas has resulted in numerous economic advantages, such as enhanced connectivity in transportation, growth in industrial and urban sectors, increased money generated from tourism, and expansion of food production capabilities.

Globally, ocean-related sectors, encompassing fishing, aquaculture, coastal and marine tourism, as well as research endeavors, provide an estimated 350 million employment opportunities and play a significant role in supporting a substantial portion of the global population through jobs and sustenance. Furthermore, it is worth noting that over one billion individuals rely on fish as their main dietary source of protein (World Bank, 2012). The marine and coastal environment serves as a crucial asset for the prominent worldwide tourism sector and the growing field of nature-based tourism.

The term 'Blue economy' has gained significant attention in contemporary discourse within Bangladesh, where it is viewed as a significant mechanism for achieving sustainable development objectives. Subsequent to the resolutions of the maritime border dispute with neighboring countries Myanmar (Jesus & Gautier, 2012) and India (PCA, 2014), the concept of the 'blue economy' has garnered considerable attention in the nation. Bangladesh now possesses a marine area encompassing 118,813 square kilometers, which includes its Exclusive Economic Zone (EEZ), situated in the Bay of Bengal with 710 km long coast line extending from the tip of St. Martin’s Island in the southeast to the west coast of Satkhira. Following the demarcation of the maritime boundary, the government is now in a position to develop policies and allocate resources. Bangladesh, being a nation with a coastline and river systems, relies significantly on its international maritime infrastructure to facilitate foreign trade.

Bangladesh possesses extensive coastal and marine resources along its southern periphery. The coastal region of the country is renowned for its great productivity on a global scale, owing to its geographical location and climatic conditions. Bangladesh possesses considerable wealth, not alone in its expansive water bodies, but also in its ecological richness. The coastal regions possess a distinctive characteristic in the form of the mangrove forests, which play a crucial role in sustaining a significant population of fish and other economically valuable aquatic species (M. S. Islam, 2003).

According to M. S. Hossain, (2001), the coastal and marine environment has gained significant importance in meeting the social and economic development goals as well as strategic objectives of the country. However, the focus of this study was limited to the examination of aquaculture and fishery resources.

2.7 Cage Culture in Coastal Waters

Cage culture is an increasingly popular form of aquaculture that has several advantages over other methods. However, its potential environmental impacts and risks to wild fish populations must be carefully managed to ensure its sustainability. By implementing best practices and using sustainable feed sources, cage culture can be a viable way to meet the growing demand for seafood while also reducing pressure on wild fish stocks. Important possible direct advantage is increased family food security through eating of nutrient-dense crops on the farm (Prein & Ahmed, 2000). According to Brummett et al. (2008), small-scale integrated aquaculture systems supported by governments and development organizations have had a significant influence on rural food security since the 1970s, despite being infrequently recognized in official statistics. IAA technology makes use of cross-system synergies in order to increase the efficiency of conventional inputs like labor, organic fertilizer, and capital while preserving the environment. Both poor and non-poor farmers are impacted by indirect poverty effects. Aquaculture increases the availability and decreases the price of fish, hence enhancing the fish supply. If only high-value species are planted, it is unlikely that the poor will benefit from these potential nutritional advantages (Irz et al., 2007). Development of aquaculture might improve full-time and seasonal employment opportunities for unskilled employees. Relative poverty is decreasing.

According to Shariff & Gopinath (2000), global cage culture varies greatly, from the storage of a few kilograms of fish in tiny nets for subsistence to salmon farms producing more than 5,000 tons annually. In Asia, around 50 species are cultivated in various types of cages. Cage culture may be tremendously profitable, but it can also be rather risky, and its success is heavily reliant on local circumstances. Salmon farming, tilapia, spiny lobster, and Asian sea bass are successful examples of variables that have led to the growth of the sector in many locations of the world. In all circumstances, robust market demand and well-established marketing networks are required. In the early phases of the development of cage aquaculture in Asia, the availability of both wild seed and low-value "garbage" fish was essential. The growing availability of pelleted tilapia feed, as well as the market's requirement for uniformity and quality.

According to Ferreira et al. (2012), the growth of aquaculture is encouraging innovation in social and cultural norms in order to meet the increasing demand for protein from a projected 9 billion people on the planet by 2050. As a result of advancements in agricultural infrastructure, limited opportunities for land-based and inshore coastal expansion, and growing attention towards offshore aquaculture, there has been a notable shift in the farming landscape. The researchers constructed a model for the gilthead bream (*Sparus aurata*) and integrated it with pre-existing shellfish models within the Farm Aquaculture Management System (FARM) model. This integrated model was utilized to investigate different facets of onshore and offshore aquaculture. The productivity, environmental externalities, and economic performance of integrated multitrophic aquaculture (IMTA) and finfish monoculture in ponds were compared using the FARM model. In contrast, the advantages of IMTA were immediately apparent. Later, the same technique was applied to offshore aquaculture, using Pacific oysters (*Crassostrea gigas*) on longlines and gilthead in cages. Due to the lack of input from these processes to the farm region, the primary production and diagenesis modules of FARM have been disabled for offshore culture. We calculate the population equivalents and credit-exchange opportunities to evaluate the environmental advantages of the IMTA. When facing offshore currents in cage culture, the finfish model in FARM clearly takes this metabolic energy cost into account. An analysis of the model reveals that gilthead cultivation is best at current rates between 0.1 and 0.5ms-1. The quality of wild fish fillets varies more towards the lower end of the spectrum; however, above this point, the feed conversion ratio (FCR) quickly rises and cultivation is no longer economically feasible.

Pantulu, (1976) investigated both Cambodia's archaic cage farming techniques and South Vietnam's modifications of those techniques. Bamboo poles and splints are used to construct cages in Cambodia, which are often reinforced with wooden boards and beams. *Pangasius, Clarias, Channa,* and *Oxyelestris* are common species planted in 40 to 625 m Super Cages. Fish are fed native plant or animal materials, and fry are obtained from natural sources. According to an evaluation conducted in 1969, there are 946 cages in use in Cambodia.

Cage culture was founded in the Republic of South Vietnam by Cambodian immigrants, but it is gaining popularity among South Vietnamese fishermen and businesses. Approximately 10,000 cages are presently functioning in the South Vietnam Republic. The size of cages ranges from 60 to 181 m, and their typical lifespan is 10 years. The most widely grown genera are *Barbus* and *Leptobarbus* (in 60.7% of cages), *Pangasius* (20.2%), and *Channa* (17.9 percent). Using weirs, traps, seine nets, and dip nets, fry are collected from natural sources and supplied at densities ranging from 80 to 361 fry/m. At a conversion rate of four, fish are fed vegetables and animals farmed locally. Depending on the species, the cultivation time ranges from nine to eleven and a half months, and the annual harvest per cage costs between two and thirty thousand dollars and three to twenty-five thousand kg. In the Republic of South Vietnam, operational expenses for cage culture are 120 to 300 percent higher than capital investment, while net returns on total expenditures range between 12 and 44 percent. Due to the fact that cage culture does not offer the same issues as pond culture, it is suggested that more effort be directed to the development of efficient cage-culture methods.

According to Xu & Qian, (2004), the growth of mariculture is primarily responsible for the increase in seafood production. Cage culture is an intensive culture with significant environmental impacts. The growth of cage culture over the past two decades has caused the marine ecology in caged regions to deteriorate. Using research published during the previous two decades, this study assesses the effects of cage culture on aquatic environments. Water pollution, sediment impact, genetic pollution, chemical pollution, and their concomitant effects on the biodiversity of coastal waters are but a few of the consequences.

Despite resource disputes and socioeconomic inequities, waste production challenges, and environmental concerns, cage aquaculture in lakes and reservoirs continues to prosper and spread, notably in Asia. Environmental repercussions emerge from the use of resources (environmental goods) and the production and release of wastes into the environment, the distribution and assimilation of which depend on the ecosystem (environmental services). Cages may have somewhat more consumption of environmental goods and services per unit of fish output than tarns. Significantly tighter is the link between environmental repercussions, the intensity of industrial operations, and the degree of growth within a lake or reservoir. Given the scale of the proposed operation, it seems unlikely that cage-based hatcheries and nurseries pose a substantial environmental concern. Such impacts may result in an increase in fisheries production in some circumstances.

According to Chowdhury & Yakupitiyage, (2000), 5488 hectares of oxbow lakes in Bangladesh have lately gained importance as a potential fishing resource. Increasing demand for this resource necessitates that resource-scarce fishing communities examine cage culture as a complement to existing stock development efforts. Investigating the existing management methods for eight lakes. The water quality of the largest lake, Lake Baluhar, was assessed. During the experiment, a lake's purity of 100 cm or more was evaluated to determine its viability for cage farming. Other indicators of water quality, such as the quantities of dissolved oxygen, ammonia, and nitrite, pointed to the appropriateness of cage culture. The majority of fishermen selected non-fisheries activities, such as agricultural pesticide usage in the lake's watershed and jute retting in its basin, as the most dangerous to fish. In the lake's catchment area, a pest management program based on rice-fish rearing systems is pushed. In addition, it is suggested that a single management system be implemented to replace the present scattered systems that are overseen by several management groups.

Rifai, (1980) employed cage culture to control the development and reproduction of *Tilapia nilotica* and compared it to pond culture. Aquatic plant species (*Hydrilla sp., Lemna sp., and Chara sp.*) and three different fish rearing densities (5, 15, and 45 fish per cage) were used. The information showed that tilapia reproduced, albeit infrequently, in both ponds and cages. Fish raised in cages experienced faster growth rates than fish raised in ponds. The utilization of *Lemna sp.* as a dietary source demonstrated superior outcomes in relation to both growth rate and protein content of fish meat. There is a limited correlation between increasing density and the act of providing sustenance.

Hambrey et al. (1999) describes the marine cage culture component of an effort to create small-scale, sustainable cage fish farming in Khanh Hoa Province, Vietnam. 1998 saw the completion of an ecological, technical, and socioeconomic study of the current state and future possibilities of grouper seed supply. Diverse existing and anticipated future methods for marine cage culture are being investigated for their viability and poverty-alleviating applications. It has been revealed that cage culture of marine lobsters and finfish is viable and may be undertaken on a modest scale in Khanh Hoa Province. Therefore, it has the potential to create extra income for the region's impoverished. The high cost and potentially insufficient amount of wild seed, as well as the lack of access to low-interest finance, appear to be the key impediments to further development at the present time. Although grouper seed may be cultivated in a hatchery, the technique is risky and challenging. Sea bass, which is now routinely farmed in Thai hatcheries, may be a more realistic alternative.

According to Gál et al. (2011), extensive cage culture has a detrimental impact on water quality due to the significant nutrient outflow from intensive fish culture. Traditional farming and intensive fish culture techniques are combined in the intensive cage and extended aquaculture system. The intense component of the system can produce important predatory fish, while the integration of an extended waterbody as a treatment unit reduces environmental nutrient loading and increases nutrient recovery in fish production. Combining cage and mere fish husbandry, a new strategy for growing predatory fish in cage. Traditional fish farmers may boost their production capacity, diversify the species they produce, and recycle nutrients by combining traditional fish farming with intensive fish cage rearing.

2.8 Seaweed Culture in Coastal waters

Seaweed culture has the potential to provide significant economic benefits to coastal communities. Seaweed is a valuable source of food and industrial products, and the global seaweed market is projected to reach $22.13 billion by 2026. In addition to direct economic benefits, seaweed culture can also create jobs and support local economies. In Bangladesh research works on seaweeds culture is negligible. There is a little amount of works conducted on seaweed in Cox’s Bazar region. Systematic field studies as well as detailed work on seaweed (culture, feasibility study, challenges, social perspectives etc.) is still in adequate in Bangladesh. Seaweed is a rich source of important nutrients, primarily trace elements and other biologically active compounds. According to history, the first seaweed was grown in Tokyo, Japan, around 1670. In 1940, it first experienced commercial cultivation. Along with Japan, several other Asian nations, including the Philippines, Vietnam, and Thailand, began farming it. Iodine, a variety of vitamins, and minerals are all plentiful in seaweed.

Every year, Japan produces seaweed worth USD $2 billion. The FAO estimates that 20 million tons of seaweed are produced worldwide. It is worth 6.5 billion dollars commercially. Bangladesh has a good possibility of seeing a blue economy revolution through seaweed cultivation due to its 710 km long coastline. Natural seaweed can be found in abundance on St. Martin’s Island in Bangladesh. As far as we are aware, there are 102 categories and 215 species of seaweed. However, several kinds of naturally occurring seaweed are slowly going extinct as a result of tourist overcrowding and municipal neglect.

Seaweeds are a critical element of the marine ecology. Seaweeds have the ability to physically dominate the whole benthic biosphere and serve as both key food supplies and homes for a wide variety of other marine species. None of the seaweed found in the oceans and seas of the world is thought to be poisonous Lindsey Zemke-White & Ohno, (1999). 2000 species of brown seaweed, 1200 species of green seaweed, and 6000 different varieties of red seaweed exist Robinson, (1980).

Seaweed has become a highly versatile substance that is commonly employed as a consumable food source for human consumption. Seaweeds are therefore great sources of nourishment for humans. People have been eating seaweed almost everywhere in the world since prehistoric times. Seaweed is a cuisine of great delicacy to the Chinese, Japanese, Filipinos, and Hawaiians, who have been using it in their diets for generations (Armisen, 1995). Seaweed could be found in coastal climates all over the world, from the balmy tropics to the very cold Polar Regions. In the past, the Romans, Egyptians, Japanese, and Chinese are said to have exploited seaweeds for a multitude of things. Dillehay et al. (2008). In the present world, seaweed use is booming in both scope and extent McHugh, (2003). Previously exclusive to Japan, China, and the Republic of Korea, the use of seaweed as nourishment for humans has now extended to massive populations in North America, South America, Australia and Europe, (Kılınç et al., 2013; McHugh, 2003).

Seaweed food products such burgers, drinks, sandwiches, cakes, salads, biscuits, chips, and others are produced commercially in addition to the traditional seaweed cuisines like Japanese Nori, Purple Laver, and Korean Wakame (M. S. I. Sarkar et al., 2016)). For a very prolonged period, seaweed has been a common staple in many different nations. Only green seaweeds, including *Caulerpa*, *Enteromorpha, Ulva,* and *Codium*, are used as food sources. These are frequently consumed with rice as cooked veggies or as raw salads. Fish and meat soups, as well as soups and accompaniments, are cooked with *Porphyra* (Nori), *Laminaria* (Kombu), and *Undaria* (Wakame) (Khan & Satam, 2003).

Although *Ulva* is grown for the worldwide food market, it is often less valuable than most other brown or red seaweed. Although it is appealing and is said to have significant nutritional content, effective marketing may boost the value, as it seems to be the recent case as consumption seems to have grown (Teas et al., 2004). Ulva species are also good as food for sea urchins or scallops (Neori et al., 2000, 2004); Particularly considering that fresh feed, rather than dried or pelleted feed, has been shown to induce quicker growth rates in abalone grow out (Troell et al., 2006).

One of the most frequently farmed genera is *Gracilaria,* which is also a key ingredient in many traditional meals and is widely cultivated for agar extraction and subsistence farming. 70 percent of the total of the agar in the world comes from members of the genus *Gracilaria.* It has previously been cultivated in complex systems as a successful phosphate remover (Salazar, 1996). It is used in experiments with genetic engineering to absorb the nutritional qualities of other seaweeds (Phang, 2010). *Ulva spp*., a kind of green algae, is regarded as a natural provider of algal proteins, minerals, carbohydrates, and micronutrients while having a low amount of lipids in its tissues. Isofucosterol and cholesterol make up this group's two primary sterols (Kapetanovic et al., 2005).

There are other possible species for culture and the way that have not been tried elsewhere, and the idea of cultured combinations of seaweed species may be more effective at extracting elements from seawater and complementing each other in cultivation (Bracken & Stachowicz, 2006). Depending on the setting and available resources, including marine and container-based culture, Australia has the potential for both vast and intense seaweed production. Seaweed farming has the ability to balance out the production of chemicals from both ground sources and marine aquaculture cages (Ridler et al., 2007).

The development of propagation and grow-out procedures, as well as the estimation of necessary ratios and amounts of water nutrients and micronutrients, will all be based on land-based, totally controlled tank culture. It will also be possible to identify any environmental or climatic needs. In comparison to alternative culture techniques, the possible integration with the expanding tank-based aquaculture business also favours becoming financially feasible in the immediate future (Neori et al., 2004; Watanabe et al., 2010). Although various seaweeds have distinct patterns of fatty acids, they are always high in polyunsaturated. For instance, some kinds of red seaweed have been shown to contain methoxy fats, which are not particularly abundant in nature.

From October to April, the whole southern coast of Bangladesh is dedicated to natural seaweeds (A. Islam & Aziz, 1977). To ascertain the current state of naturally occurring seaweeds in Bangladesh, significant water sampling and specimen extraction from exposed rock surfaces during tidal cycle might be carried out. St. Martin's Island and the Sundarbans Mangrove Forest in Bangladesh are typical locations for seaweeds to be found in the littoral and sub-littoral zones (A. Islam & Aziz, 1975, 1977). The Sundarbans provide favourable conditions since they meet the requirements for the growth of seaweed, which include salinity of 2–24 ppt, PH 7.5–8.5, and 20–30° C (Satpati et al., 2012).

Poor seaweed development is anticipated in the Sundarbans compared to other locations in Bangladesh where seaweeds are naturally accessible because of the presence of colloidal debris from tidal silt, decomposing leaves, etc. in the water that prevents light penetration (Satpati et al., 2012). There are numerous seaweed species in the Shaplapur coast, Shahparirdip region, Nuniarchara, Nazirartek of the Bakkhali-Moheshkhali river estuary, Jaillapara of Teknaf, and planted tropical woods or Parabon region (Haque et al., 2010). According to several studies (Tomascik, 1997; Zafar, 2005) , the water chemical characteristics appear to be very favourable for seasonal abundance of seaweed.

2.9 Conclusion

Mariculture has the potential to provide significant economic and environmental benefits, but there are still many challenges that must be addressed in order to develop a sustainable and profitable industry. Further research is required to improve cultivation techniques, develop new products and markets for seaweed and cultivated fish in the cage, and address environmental and social concerns associated with seaweed and cage culture. From the literature review it was observed that there were several research on physicochemical properties, phytoplankton, zooplankton, nutrient and heavy metal in the coastal waters on different part of the world even some in Bay of Bengal but such research in the coast of St. Martin’s Island is lacking. Exploring the possibilities of mariculture is the main objective of this study. In order to accomplish the objective, it is necessary to determine the abundance and distribution of physicochemical properties, phytoplankton, zooplankton, nutrients, and heavy metals in the coastal waters of St. Martin's Island during the different seasons of the year. This will ease the development of a comprehensive framework by determining the suitable site, season and species of fish and seaweed for mariculture, which has the potential to enhance the blue economy of St. Martin's Island as well as the entire nation.

Chapter 3 **The St. Martin's Island**

3.1 Study Area

This chapter provides an overall view of the study area. St. Martin's Island was chosen as the pilot area to explore the possibilities of mariculture. The Island is known for its diverse marine life and coral reefs, which have attracted marine biologists and environmental scientists to conduct research on the island's ecosystem. Additionally, St. Martin's Island is widely recognized as a renowned tourist attraction, making it a hub for social and cultural research on topics such as tourism, migration, and multiculturalism. Overall, St. Martin Island's location, geography, and cultural diversity provide ample opportunities for researchers to conduct a wide range of studies in various fields.

3.1.1 Study area location

The St. Martin's Island lies in the Bay of Bengal's northeastern part between 20˚ 34' and 20˚ 39' of N latitude and 92˚ 18' and 92˚ 2' E longitude (UNDP, 2010). The island has a total landmass of approximately 8 km², almost half of it are rocky platforms in the sea (DOE, 2012).

Figure 3.1: Map of the Study area–St. Martin's Island

St. Martin's Island, a geographically isolated landmass, is situated in the northeastern extremity of the Bay of Bengal, approximately 12 kilometers to the south of the Cox's Bazaar-Teknaf Peninsular tip in the country of Bangladesh. During high tides, the island appears as two separate islands due to a narrow channel (94m wide and 2m deep) that separates it from the nearby Chera Dwip Island.

3.1.2 Environmental Geology

The island of St. Martin has a variety of marine deposited rocks that range from the late Miocene period to the present (Samia Saif, 2010). The southern part of the marine layer appears to be from the late Miocene era and is covered by a Pleistocene-era coquina bed, as well as Holocene-era alluvium and beach sands. The island's geographical features include rocky platforms, sandy beaches, sand dunes, lagoons, marshes, tombolo, crenulated shorelines, and coral clusters. The main types of rocks found on the island include argillaceous limestone, calcareous sandstones, fossil conglomerates, and caroline limestone. The island also has a ring of sand dunes in the north, southwest, and west, with fewer in the east, and a shoreline that is more or less crenulated. The foundation rock of Narikel Jinjira has a sedimentary origin consisting of tertiary sandstones, interspersed with shell reservoirs (Samia Saif, 2010).The blocks discovered in the intertidal and subtidal areas are mostly sedimentary in origin, and likely the rock basis remains (Tomascik, 1997). Some boulders intermingled with dead coral colonies (the source and presumably the continuation of the foundation rocks) (Tomascik, 1997). Some spherical rocks, interspersed with dead coral colonies, are presumably created by the accretion process. The Island is positioned on the eastern flank of an anticline, presumably a component of the folded Arakan-Naga system, according to Warrick et al., 1993), hence the island could be considered a sedimentary continental island that supports various coral ecosystems.

3.1.3 State of the Environment

The surface temperature of the water of the island is 18-31^{0}C (Tomascik, 1997), and hence is of the optimum range is 20-30^{0}C. The shoreline water salinity of Narikel Jinjira ranges between 26 and 35 ppt, as measured in a few occurrences during dry seasons (Tomascik, 1997). Because of the increased freshwater input from the Naaf River during July to October (rainy season), the level is expected to drop even further. This level is therefore below ideal which is 32–36 ppt.

However, in some places of the planet, certain species can endure low salinity (Tomascik, 1997). The average maximum air temperature ranges from 27 to 32 degrees Celsius, while the minimum temperature ranges from 16 to 26 degrees Celsius. The level of relative humidity in the island is less, around 67% in February and higher in July around 90%. From the months of October to February, the climatic conditions are characterized by moderate temperatures and a relatively low amount of precipitation, ranging from 0 to 88 mm. The occurrence of storms characterized by high levels of precipitation, ranging from 239 to 309 mm, is observed throughout the period between March and May. The Southwest Monsoon season transpires during the months of June and July, throughout this specific time period, the temperatures range from 30 to 35 degrees Celsius, which is notably higher compared to the other months of the year. According to DoZ, (1997) and Tomascik, (1997), the months of August and July are characterized by a transition period marked by a decrease in precipitation and a decline in temperature. Nevertheless, due to its geographical location surrounded by the ocean, the island has relatively higher minimum temperatures and lower maximum temperatures in comparison to Cox's Bazar (Tomascik, 1997). The region consistently encounters elevated levels of humidity throughout the year, as indicated by an average humidity level of 79.7% (M. N. Islam & Roshid, 2018). According to Tomascik, (1997), the saline level of the coastal waters of St. Martin's Island experiences variations ranging from 26 to 35 parts per thousand throughout the dry season. The tidal regime of St. Martin's Island exhibits natural semi-diurnal tides, characterized by the occurrence of two high tides and two low tides within a 24-hour period (Banglapedia, 2010). The tidal range observed on the island is around 1.87 meters, a value comparable to that of Shahpuri Island, situated approximately 9 kilometers northeast of St. Martin's Island. During high tide, the area known as Chera Dwip becomes submerged and extends from the mainland.

3.1.4 Topography

St. Martin's Island is situated at the estuary of the Naf River. The distance between the Cox's Bazar-Tecnaf River point in the south and the coast of Myanmar in the northwest is 9 km and 8 km, respectively. It is the southernmost section of Bangladesh. The island is relatively flat, with an elevation of 3.6 meters above sea level. The island is divided into five distinct physical areas (UNDP, 2010):

1. Uttar Para,
2. Golachipa,
3. Madhya Para,
4. Dakhin Para, and
5. Cheradia

The weather patterns experienced on the island are shaped by the monsoonal subtropical climate characteristic of Bangladesh, although it is located in the tropical belt. The island is divided into a larger northern section and a smaller southern section, with a narrow boundary separating the western and eastern beach sand dunes. This thin area is gradually eroding from both sides. The island is made up of sedimentary continental rocks from the mainland, with coral ecosystems colonizing it. The underlying rock is the Girujan Clay shale (Pliocene) with subordinate gray sandstone intermingling with it (UNDP, 2010). The island's soil is primarily composed of muddy sands assorted with calcareous residues from the sea. The water temperature on the surface of St. Martin's Island ranges from 18 to 31 degrees Celsius, and the salinity of the coastal water ranges from 26 to 35 parts per thousand (Tomascik, 1997). The turbidity of the water inside the island varies between 1.5 and 8.0 meters, varying on the sea level and the tide cycle. (UNDP, 2010) .

The geographical features of St. Martin's Island are characterized by a coarsely shaped landmass, measuring approximately 7 kilometers in length and 500 meters in breadth at its maximum extent. The topography of the area is predominantly characterized by a relatively low elevation of 3.6 meters above sea level. The island's total land area is around 600 hectares or 6 square miles. Bangladesh is situated on the northern side of the island, while Myanmar occupies the north-south shore and the western region adjacent to the open sea.

The island contains five different physiographical zones as mentioned. The northern part of the island is the Uttar Para, with a maximum length 2134 m and a width of 1402 m, on the north-south axis. The thin strip of land that connects Uttar Para to Madhya Para is named as Galachipa. The south area of Golachipa is Madhya Para and is 1524 meters long and 518 meters wide at its widest point. The southern part of the island is Dakhin Para which is 1929 meters long and 1890 meters narrow to the southeast, with an additional tail that stretches up to 975 meters wide (Roy, 2021).

The rocky reef, named Chera Dwip, is approximately 1.8 km long, between 50 and 300 meters wide, and located on the south-east side of Dakhin Para. This region has been recently designated as an Ecologically Critical Area (ECA). The island is relatively flat and has an average elevation of 2.5 meters above the Middle Sea Level (MSL), with cliffs on the eastern coast rising up to a maximum of 6.5 meters (Ahmed, 1995; Warrick et al., 1993).

Dead and fossil corals are abundant in the southern part of the island in the upper coastal areas. In the underwater rocky substrate, which is flooded at high tides, living corals are observed. There are no coral colonies in the muddy and sandy substratum. The densely populated area with various coral families is eastern portion of Galachipa, the stony area of Cheradia, the southern coast of Dakhin para and the south-east coast of Dakhin para.

It has been connected to the continent of Teknaf Peninsula 6000-7000 years ago recently (Chowdhury, 2012; Warrick et al., 1993). About 250 years ago, Arab sailors established the first settlement on the island, calling it "Zajira," but it was later renamed St. Martin's Island by the British. However, it wasn't until the 1880s that the local colonies on the island began to form. Later on, it was locally referred to as Daruchini Dwip and Narikel Gingira (M. Z. Islam, 2002).

It is a stubborn island with a length of approximately 7.8 kilometres, with some hundreds or little around 1 km, a low tide area of around 8 km^2 and a high tide of around 5 kilometres. The island is positioned on a shallow, 25 meters deep continental shelf. Narikel Jinjira's highest coastal depth is about 10 meters (DOE, 2012).

3.1.5 Demography

Presently, the population consists of roughly 6,000 individuals, with over 3,700 residents mostly engaged in fishing activities. Additionally, tourism, agriculture, and day labor serve as significant means of sustenance for the local community (Thompson & Islam, 2010).

3.2 Diversity of Ecosystems

3.2.1 Habitat of Rocky Area

The area of rock is roughly one km long and is the only habitat remaining for several unique species, including Bengal cobra (*Naja Kaouthia*), the water monitor (*Varanus Salvator*), water birds, garden lizards, and bush birds, as well as native climbers, herb and shrubs. Particularly during winter season, the shallow water pools and rocky terrain provide an excellent terrestrial microhabitat.

3.2.2 Sand Dunes and Beaches

The main coastal ecosystems consist of sandy beaches and dunes, with alluvial sand being the predominant type of deposit. These beaches are considered to be the most significant nesting areas in Bangladesh for marine turtles, which are internationally endangered (Kamal, 2008).

3.2.3 Lagoons and Wetlands

The island is home to a variety of mangrove and flatland lagoons and wetlands, which are believed to serve as crucial habitats for avian species. According to the United Nations Development Programme (UNDP, 2010), Uttar Para is characterized by the presence of a lagoon, whereas Dakhin Para exhibits a freshwater humidity and expansive flood lands that extend around the island.

3.2.4 Coastal Vegetation/ Mangrove

Undoubtedly, the island formerly contained a huge amount of mangrove floras most of which has been destroyed now. The *Lumnitzera racemosa* dominated the top of the canopy, and there were 29 kinds of mangroves (Tomascik, 1997). A very minor rest of mangrove patch is now available on the site.

3.2.5 Mudflats

Located within the cross-tidal region, a small mudflat area called as Gaitta Banya can be observed. The geographical position of the area in question is situated on the southern portion of the western coastline. Based on the UNDP report from 2010, it can be observed that the island only harbors a single population of either the yellow-lipped sea krait or the colubrine snake.

3.2.6 Marine Ecosystem

Low-water marine habitats include coral aggregations, seagrass beds, soft coral habitats, offshore lagoons, rocky sub-tidal habitats, and rocky or sandy intertidal habitats (Chowdhury, 2012).

Numerous fish and fish species of major commercial value can breed and grow in the vast algal and seaweed beds that are abundant and diverse in the island's coastal waters (Kamal, 2008). There are only a few places in the world where coral ecosystems predominate over stony reefs; St Martin's Island offers a special combination of environmental factors that are absent from the rest of Bangladesh and perhaps the entire world.

3.3 Diversity of Flora & Fauna

Despite the loss of numerous flora species, the botanical composition of St. Martin's Island exhibits notable dissimilarities due to the introduction of a considerable quantity of produced species alongside the existing natural species. In recent floral surveys, 150 herbs, 25 shrubs, 32 climbers, and 53 trees from 58 families have been identified (UNDP, 2010). On the island locally known as Narikel Jhinjira, large amounts of *Cocos nucifera* (also known as Narikel) are cultivated. The island's richest tree is thought to be *Streblus asper* (locally known as shaora) (Tomascik, 1997). According to the United Nations Development Programme in 2010, the predominant natural tree species in the region are two varieties of *Pandanus,* commonly referred to as keya, and one species of *Streblus*. The prominent shrub species in the area include *Vitex trifolia*, often known as Nil-nishinda, and *Vitex negundo*. The most notable plant is Shagor lota, scientific name *Ipomoea pescaprae*. *Allium sp.,* a species of onion that belongs to the Alliaceae family and is only grown in Bangladesh, is indigenous to the island. *Hibiscus tiliceous, Acanthum ilicifolius*, *Avicennia marina, Sonneratia apetala, Clerodendrum inerme,*and *Excoecaria agallocha* are the remaining species of the mangrove forest (Tomascik, 1997). Early settler, *Aegialitis rotundifolia*, is extinct from the island (UNDP, 2010). 154 marine algae, mostly from the inter-tidal and littoral zone of the island, have been identified (Tomascik, 1997). For many animal lives in the water, marine algae are a major nutritional resource.

According to Tomascik (1997), there were only nine species of echinoderms found on the island, which were divided into eight genera from four classes of the phylum echinoderm. These nine species included sea urchins (4 species), sea star (1 species), nudibranchs (3 species), and one sea cucumber (1 species).

St. Martin's Island is the sole geographical region within Bangladesh that possesses a favorable ecological environment, hence making it the exclusive habitat for coral colonies. The island is 200 meters offshore, surrounded by coral colonies. There are 66 species of coral, 19 of which are fossils, 36 of which are living corals, and the remaining six are soft corals(octocoral) (Tomascik, 1997). The most prevalent genera include *Favites, Goniopora, Porites, Cyphastrea,* and *Goniastrea*. A distinctive characteristic of the subtidal zone is the soft coral community on the eastern shore of St. Martin's Island (M. Z. Islam, & Islam, 2008). There are 187 different species of mollusks on the island, 44 of which are gastropods and the rest are bivalves. There are several commercially important gastropods, including *Trochus niloticus* and *Turbo marmoratus*, which are severely depleted around the world, as well as *Conus striatsus*, *Conus textile*, and *Conus geogrphes* (Tomascik, 1997). There were about 12 different species of crabs on the island, including those that are important commercially, such as the mangrove crab *Scylla olivacea*, which is widespread in Bengal Bay (Tomascik, 1997). St. Martin's Island in Bangladesh's fish and fishing resource is unquestionably highly rich in species variety. There are a total of 234 kinds of fish in the seas around the island, 89 of them corals and just 16 of them freshwater fish (UNDP, 2010). Damsel, parrot, Surgeon, Group, snappers, emperors and butterflies were the most numerous reefs or coral fish linked with it. On the island, 27 species of reptiles totaling 11 families and 3 orders have been identified, 11 of which are locally threatened (Tomascik, 1997). *Eretmochelys, Lepidochelys olivácea,* and *Chelonia mydas* are three kinds of sea turtles that are reported on the island. There are four amphibian species found in the island. They have three: *Hoplobatrachus tigerinus, Euphlyctis cyanophlyctis,* and *Polypedates maculatus*, the Common Asian Toad (*Bufo melanostictus*). The area provides a stepping stone for many migratory or coastal waders as it is located at the border or crossing of the East Asia-Australia Flyway and the Central Asian Flyway. There have been 120 bird species documented in all (77 permanent species and 43 migrant species), with 18 of them possibly being locally endangered (Moudud, 2010; Tomascik, 1997). There were 19 different types of animals on St. Martin, and the only terrestrial carnivore on the island is the dog. According to the (UNDP, 2010), it is alleged that the waters surrounding St. Martin's Island are home to six distinct species of marine life, which include cetaceans such as *Tursiops aduncus, Orcaella brevirostris, Stenella attenuate, Neophocaena phecaenoides, Sousa chinensis* and *Stenella longirostris.*

3.4 Land Usage

A comprehensive resource plan was produced by considering the geographical distribution of various habitat categories depicted on the map, encompassing plains, intertidal zones, sandy shoreline, rocky coastlines, mangrove forests, algal beds, coral areas, fishing grounds, and wetlands. The land utilization on the island encompasses agricultural activities, human settlement, the presence of Screw pine or umbrella trees, and the existence of mangrove forests.

3.4.1 Plain land

A significant portion of the flat terrain is allocated for agricultural purposes, human settlement, the establishment of infrastructure, and various other human activities. The absence of water logging on the island can be attributed to the rapid flow of rainwater.

3.4.2 Intertidal Zone

The intertidal zone, encompassing the area between the high and low tide lines, spans around 398 acres, rendering it bigger in size compared to the island itself. The intertidal zone harbors a diverse array of crustaceans and arthropods.

3.4.3 Mangrove Forest

In the southwest shore of the Island the mangrove forest occupies around 15 acres. The forest of mangroves is nearly stony with coarse rocks of sand. This is a unique co-existence of mangrove forests on the rocky substratum (*Avicennia* and *Rhizophora species*). The trees are 1.5-2.0 m high and the branches in the brook are spread. Natural regeneration has not been shown. There are no damage or care of the mangrove wood in the local community. The powerful physical processes on the shoreline may hinder the development of the mangrove forest (Hossain et al., 2007).

3.4.4 Sandy Shore

In one area of the island's northeast, sand beaches extend for about 5 kilometers, with an average width of around 100 meters during high tide. During a low tide, a sand flat up to one kilometer wide with regions of dead coral and stones is exposed. At the beach, people can bathe, sunbathe, and swim. The sandy coast of the island measured about 110 hectares in total. The sandy zone was chosen as the main walking road because the access to the island has not yet been created. Fish drying, shipbuilding and maintenance, local trade, and other domestic tasks are all carried out in this region. Sea turtles use the sandy coast to lay their eggs (Hossain et al., 2007).

3.4.5 Rocky Shore

Except for the northeastern side, the rocky beach is enclosing the island. At low tide in the southwest and southeast, the rugged area extends for around 0.8-1.0 km and 2-2.5 km. The rocky area encompasses around 364 acres, mainly disappeared around high tide. The rocky beach on the east side has average width of around 200 m and a maximum of 500 m although the west end is very small. In rocky areas, the majority of attachable molluscs, especially oyster, green mussels and barnacles, stay completely unused. These species are not handled, as they are not regarded fit for feeding the islanders for cultural rather than religious reasons. Over the last few years the islanders have collected stones from rock pools and used the building of homes, roads and walking paths to substantially destroy rock pools (Hossain et al., 2007).

3.4.6 Wetlands

The Island comprises 5 fresh-water wetlands, 3 of which are 2.7 hectares in the north of the island and the other 2 are 4 hectares in the south. The island exhibits distinct features in the form of two streams. One stream is positioned along the northwestern shoreline and has a length of approximately 1 kilometer, whereas the second stream is placed on the eastern shoreline and extends around 500 meters inland. Ten gates were installed to drain rainwater and tide-water, however the islanders say that water logging occurs after heavy rains since there are insufficient drainage facilities. Little swamps and wells, usually located near the village and utilized for domestic chores, were identified during field surveys (Hossain et al., 2007).

3.4.7 Elevation

Uttarpara is the largest portion of the island with an overall width of roughly 2 kilometers to the north and diminishes to roughly a quarter of a kilometer and it is then extending to the south again gradually. The South section is around 7 feet above sea level, and the North section is about 8 feet above sea level (A. Islam, 1970).

3.4.8 Important Installations

This island is well known for light posts, which may be used for navigation. The coast guard, naval base, police, post, boys' club, and cooperative of fishermen are the most significant organizations. There are so many hotels and resorts are situated in the area for tourist. Additionally, the island has three cyclone shelters to shield residents from natural disasters (Hossain et al., 2007).

3.5 Activities in the Island

3.5.1 Deforestation: The island's persistent deforestation can be mostly attributed to the utilization of wood for cooking purposes and the construction of buildings. A huge population has significant daily needs for burning wood, yet many poorer people cannot afford to buy the timber imported from Teknaf. The majority of the time, small, bushy plants have been chosen. Another significant factor in the recent deforestation is the removal of vegetation like mangroves in order to meet demand for land. Coral growth is hampered by increased water turbidity and sedimentation brought on by deforestation.

3.5.2 Agriculture: 116 hectares of the Island's land are used for agricultural, while another 7.4 hectares are used for household gardening, making about 37 percent of the island's overall land use. Chili and watermelon are the major crops grown mostly in the island's north (Uttar Para). There is also a small indigenous onion species and little maize is cropped with chilli. Chilli is cultivated in this region. In the rainy season a limited amount of transplanted Aman rice is grown. The original vegetation has been replaced by planting trees, particularly cocoa. The home-growing of coconut is a significant source of income. Additionally, certain species produce wood. Livestock is also raised; however, just 182 cows, buffalos, and 219 goats were registered in 2000 (M. Z. Islam, 2001) which is down from 360 cows and 329 goats in 1996 (Tomascik, 1997), 33% of households registered their own animals in 2005.

Agriculture causes continuous habitat destruction, particularly the clearing of rocky soils for cultivation and lagoon replenishment. Additional issues include the cultivation of native and hybrid plants, as well as the application of artificial fertilizers and pesticides. During the rainy season, agricultural runoff may have a substantial impact on coral supplies due to water turbidity sedimentation and turbidity of water (Tomascik, 1997).

3.5.3 Tourism: Every year thousands of tourists visit the island, mostly from December to March when the weather is suitable. Given the current management level, this number of visitors exceeds the site's carrying capability. Infrastructure facilities for the tourism industry are being created, although they are not planned or EIA-compliant. Uncontrolled and insufficient waste disposal is a big problem caused by tourism. Untreated waste is directly drained into the sea or deposited in open pools that adversely affects the quality of the marine and groundwater. This has led to the extreme degradation and the purchase or collection by tourist of huge quantities of coral and shells(Baruaa et al., 2020).

3.5.4 Water Extraction: The island's ground water lens has been damaged by deforestation and extensive agricultural growth (Tomascik, 1997). One well got dry and some became saline during the 1996 (Tomascik, 1996). Freshwater is accessible on the Island at a shallow depth of 10 feet (M. Z. Islam, 2001). Local residents' increased reliance on freshwater and the enormous influx of tourists each year, which coincides with the dry season, have led to a decline in the water table. The near future can only see a rise in this need. In order to meet demand and further lower the water table during the busiest tourist season, motorized pumps are now employed, making it more difficult for locals to acquire water from tube wells (M. Z. Islam, 2001).

3.5.5 Marine Invertebrate Collection: Keystone species, such as molluscs and sea cucumbers, are being removed on a huge scale from intertidal and subtidal ecosystems, which is an issue. In the lower intertidal zone, shells are taken from the beach and sold as souvenirs. In 2000, shell collectors made up about one-fifth of the 332 family heads working in the natural resource mining industry (M. Z. Islam, 2001). Previously, only larger shells were collected, but today, even minute shell species are collected. Living molluscs are increasingly being collected since the shell resource has been overused. Sea cucumber is also widely utilized (Baruaa et al., 2020).

3.5.6 Seaweed Harvesting: The local community has confirmed that one species of seaweed is harvested and traded in large quantities to Myanmar. The seaweed is usually picked up from February to April in its dry shape, which is determined by weight. 32 (10 percent) of the 332 households working for natural resources were involved in the harvesting of seaweed in 2000 (M. Z. Islam, 2001). For initiating the creation of sand dunes, seaweed is essential.

3.5.7 Coral Extraction: Beginning in the 1960s, a number of families have made a living by collecting corals for commercial purposes. Almost one-fifth of 332 family leaders engaged in the development of natural resources in 2000 were coral collectors (M. Z. Islam, 2001). Coral collects when there is calm sea, clear water and favorable tides between October and April. From 1995 to 1997 the survey conducted by NCSIP 1 revealed that corals are collected at the depth up to 5 m by at least 11 small non-mechanized boats, while others without boats walked up to approximately 2m to collect it. The coral is broken by a hammer and a chisel. The key types collected with *Acropora spp* were *Favia* and *Goniastra spp*. 40–100 kilograms of coral were harvested per day per boat, or roughly 20–40 kg per day per person. It is calculated that 24% of the current coral population will be lost annually (Tomascik, 1997).

3.5.8 Fishing: Fishing and drying of fish are traditional activities on the island, with over 600 trained fishermen and 170 fishing boats there in 2000–2001(M. Z. Islam, 2001). Between September and April is the primary fishing season, with each boat hauling on average 11 metric tons of fish. The primary fishing equipment is the seine net, gill, drifting and fixed, nets. The fish are caught from the offshore coral beds. Boulder reef fishing on coastal waters is conducted with rock-weighted gill netting with detrimental repercussions for corals. Most of the fish are sun-dried in 5 big fish-dried farms and in the various households and then transported to Cox's Bazar and Chittagong dealers. How many chemicals are used in fish processing, as well as how their use affects the environment of the shore, are unknown. The collection of shrimp fries on the island is also undertaken and fried is supplied to the suppliers of shrimp fried Cox's Bazar shrimp farms. The large-scale loss of many other marine species is caused by shrimp fry collection (Baruaa et al., 2020).

3.6 Islanders' Socioeconomic Circumstances

Numerous natural resources on the island have contributed significantly to the socioeconomic growth of the islanders. The main stakeholders are fishermen, farmers, coconut sellers, coral harvesters, mollusk shell collectors, and seaweed collectors. Some domestic workers have also worked in other industries, such as agriculture, shell-fishing and fishing. Diverse coastal resources, including fishing, sandy and rocky shorelines, sand dunes, mollusk shells, coral reefs, ornamental fish, mangrove forests, and sea weeds, a strong fishing commitment, an excellent geographic location for easy access to the seaside, and beautiful natural beauty for tourists are the island's main strengths. For non-commercial fishing of cephalophods and crabs, mollusks, and ornamental fish, value addition and new market potential are significant opportunities. Tourists must develop small-scale cocoa and cottage industries and develop ecotourism marine environmental facilities to monitor and not harvest marine organisms in their own natural habitats. But the limitations are analphabetism, lack of technological knowledge, limited land resources, insufficient transportation facilities, lack of information of the islander's opinions during decision making, indiscriminate use of resources etc. Lack of efforts to increase the technical knowledge and expertise of farmers, agriculturists, livestock farmers and others; failure to integrate policymakers; unplanned tourism operations without environmental capability; lack of understanding about community development are key challenges.

3.7 Environmental Threats to Biodiversity and Ecosystem

3.7.1 Climate Change's Effects on the Island

The impacts of climate change pose major dangers to St. Martin's Island's biodiversity. Coral bleaching is the most obvious impact from rising water temperatures. Coral bleaching becomes colorless, hideous coral. As a result of rising temperatures coral reefs have already experienced a significant mortality rate. It also depends on an algae species that symbiotically dwells in its body and provides additional nourishment through photosynthesis. If the water temperature is higher than 28 °C, the coral expels the algae and becomes hungry. Beaches where turtles lay their eggs erode due to sea level rise. The increased sand temperature causes changes in sex ratios or avoids hatching of eggs. Coral reefs are critical sites for turtle feeding. Bleaching coral harms turtles' nutrition supplies. Huge precipitation can elevate groundwater levels and hence flood turtles' nests (UNDP, 2010).

3.7.2 Coastal Erosion and Deforestation

In the course of the past several decades, deforestation on St. Martin's Island has expanded alarmingly. The population density of the island is mostly attributed to the destruction of its forests and the extraction of sand dunes for fodder and fuel wood, which in turn leads to an increased occurrence of natural catastrophes. The destruction of vegetation including mangroves in order to claim land by local people is another important source of recent deforestation (Ahmed, 1995). Although coastal erosion is a usual procedure, unrestrained flora losses hasten erosion that cause sedimentation and turbidity which are detrimental to growth and survival of the coral.

3.7.3 Unregulated Tourism

Due to recent improvements in tourism infrastructure, the island of St. Martin, which has long been a popular tourist destination for Bangladesh, has become even more so. The current tourism business has a major influence on the area's ecological viability. In peak seasons (November through February) more than 3000 people visit each day and opt to spend the night on this little island. However, the delicate island environment isn't ready for this. Timeless structures for tourist housing like hotels, motels and restaurants have risen quite rapidly as a result of heavy growth in some regions, which is mostly frightening of the region's ecological balance. Corals and sea turtles are St. Martin's island's principal biodiversity and are endangered by tourists. Sea turtles' nest between 10.00 to 02.00 AM on the island's beaches. It is observed that hotel and motel generators are used for visitors until midnight, which is a further reason why the number of nesting turtles is troubled as much as decreased in the quantity. Tourists encounter most popular activities during their visit to snorkeling and scuba diving because inexpert scuba divers and snorkelers like to stand on reefs, these actions have been linked to a major risk to corals in shallow seas. A vast amount of coral, different types of shells and star-fish has been bought and collected by tourists which have led to the serious loss of such species. The winter bird migratory season coincides with the summer tourist season of the year, when the birds' usual life is hindered by huge stretches of preferred coastal habitat. There are regular large ships and engine boats that take visitors, and so significant quantities are released into the sea water nearby the island which ultimately depletes fish and other marine creatures from raw oil, plastics and other non-biodegradable garbage.

3.7.4 Indiscriminate Extraction of Natural Resources

The biodiversity of St. Martin's Island, its intertidal, subtidal, coasted ecosystems, and its surrounding coastal waters are continuously at risk due to the extensive removal of keystone species and other marine resources for food or as attractive souvenirs (such as algae, mollusks, and lobsters). While marine algae are crucial to stop soil erosion and maintain and enhance the beaches, they are harvested for selling to Myanmar in great amounts by the local people (Kamal, 2008). The nesting turtles have been endlessly over-exploited. The main consumers of turtle eggs are the ethnical populations and the largest commercial areas are Khagrachari, Rangamati and Bandarban's three hill-stretch districts. The practice of commercial coral harvesting was initiated during the 1960s and continues to serve as a significant economic resource for numerous individuals in the present era (M. Z. Islam, & Islam, 2008).The biggest threat to the continued community's existence is direct excavation of colonies of corals. Over the shore, alive mollusks and shells are currently being plundered. Due to overfishing and the sale of sea urchins to curious traders and tourists, the sea cucumber species *Holothuria atra* is found in extremely limited numbers. Additionally, a number of fish species are being overfished, and fishery diversity has significantly declined recently (Feeroz, 2009).

3.7.5 Other Environmental Negative Factors

Six families immigrated from Myanmar permanently to the island about 150 years ago (UNDP, 2010). Today the island is home to around 6,000 people (Feeroz, 2009).The biological variety of the island is additionally greatly threatened by the population. The local people are expected to depend significantly on the island's natural resources for its subsistence, because it lacks alternatives for life. The continuous degradation of ecosystems, notably the clearance of rocky ground for agriculture and the reclamation of lagoons, are caused by farming, one of the principal activities by local population. Additional difficulties include the growing and usage of chemical herbicides and fertilizers for exotic or hybrid plants (Feeroz, 2009). Floods and strong runoff during rainy seasons have a significant effect on coastal ecosystems and transfer enormous amounts of sediments, fertilizers and pesticides from poorly controlled agricultural fields to coastal waterways. Furthermore, the flora and wildlife of the island has been endangered by cyclones, storm surges, hazardous ship anchor practices, damaging fishing gear and other anthropogenic activities.

Chapter 4 **Mariculture**

4.1 Introduction

This chapter provides an overview of mariculture. The concept of "mariculture" encompasses the systematic administration, cultivation, and extraction of marine organisms, either within their native environments (such as estuarine, brackish, coastal, and offshore waters) or within controlled enclosures such as cage, pens, tanks, or channels. Seaweed, mollusks, crabs, fish, and echinoderms are just a few of the creatures that are grown. Aquaculture operations can be very extensive or very intensive, as with other forms of aquaculture. On the opposite end of the spectrum, there exists a practice known as intensive mariculture, which takes place within a confined system. In this system, the farmer has responsibility for supplying all necessary nutrients, while also ensuring the maintenance of the environment through processes such as water filtering, sterilization, and oxygenation. Additionally, the farmer exercises control over the light and temperature conditions within this system. Extensive mariculture primarily revolves around safeguarding the stock in order to enhance the survival rates of juvenile organisms in their natural habitat. Ranching is another type of mariculture where young animals raised in a hatchery, primarily crustaceans and salmonids, are released into the ocean where they graze and develop similarly to their wild counterparts. Ranching has low survival rates, but the costs are lower than they would be for a large-scale farming enterprise.

Farming marine organisms is a specialized branch of aquaculture known as mariculture. If seafood production from catch fisheries will rise or fall is unclear. However, if mariculture is carried out sustainably, it may increase the supply of seafood. From 14% in 2000 to 35.9% in 2016, mariculture's share of the world's aquaculture production has grown significantly during the past ten years. According to the Sea Around Us worldwide mariculture database (www.searoundus.org) 5 million tonnes were produced in 1990; by the end of 2010, this production had climbed to 21 million tonnes. The surge in the need for high-value omnivore, carnivorous finfish, crustacean species, and marine bivalves in developed nations has been associated with the amplified production.

Despite the desire to enhance mariculture in order to produce more seafood, worries about its effects on the environment and the lack of sufficient space are also growing. Environmental concerns, such as organic farm waste from mariculture activities, can cause eutrophication and organic enrichment of sediments, which can then alter the physicochemical characteristics and microflora biodiversity of benthic sediments in and around mariculture sites. Moreover, fishmeal and oil, predominantly sourced from small pelagic forage fishes, play a vital role in aquafeed composition, particularly for omnivorous and carnivorous species in aquaculture. Consequently, the demand for fishmeal and oil exerts pressure on wild fish populations. Mariculture has the potential to induce pollution through the utilization of pharmaceuticals, antibiotics, and the contamination of heavy metals. Additionally, it can lead to the introduction of non-native species, genetic interactions, the spread of diseases, and the depletion of coastal habitats such as mangroves.

There are several attempts being made to determine the area that would be ideal for mariculture production among other maritime activities (e.g., energy production, shipping, marine protection, and fishing). According to research, there is a considerably wider global region that would be a good place for mariculture than there is right now. Oyinlola et al. calculated the total acceptable mariculture area for the 102 species to be 72 million km^2, using species distribution models. For shellfish 31 million km^2, for 39 million km2 of crustaceans, and for finfish in 66 million km^2, is good for mariculture. This forecast covered regions that are currently used for mariculture. The report also identifies regions with the greatest potential for mariculture, including West Africa and the southwestern Atlantic coast. Some notable areas with a high diversity of mariculture species include the Caribbean Sea, the East China Sea, the Yellow Sea, the Sea of Japan, and the Banda Sea off the coast of Timor-Leste. Despite data that indicate these potential mariculture sites have great species richness, the majority of the species are not already farmed in these areas.

Through an increase in job and livelihood prospects, mariculture's continued expansion can help address issues with food security and the development of producing nations, particularly in locations with sizable maritime habitats. Presently, mariculture serves as a significant contributor to the gross domestic product (GDP) of more than 112 countries and territories, with a majority of these nations falling under the category of developing countries. The future sustainability of mariculture has the potential to exert substantial impacts on these nations. The creatures that are cultivated encompass a diverse array of species, namely fish, seaweeds, crustaceans, mollusks, and echinoderms. Fish culture in cage/ Cage culture and Seaweed culture was focused in this study.

4.2 Cage Culture

During the early 1900s, cage culture techniques were discovered in Southeast Asia, particularly in the freshwater lake and river systems of Kampuchea. The origins of marine fish farming in cages may be traced back to the study conducted at the Fisheries Laboratory of Kinki University in Japan. This research, which focused on the cultivation of yellowtail Seriola quinqueradiata, ultimately led to the establishment of a thriving business by 1960. Thailand has made advancements in the cultivation of marine finfish, specifically the sea bream (*Pagrus major*) and grouper (*Epinephelus spp.*), through the implementation of cage culture techniques since the 1970s. Large-scale grouper cage farms were established in Malaysia in the year 1980. The practice of cage culture for olive flounder (*Paralichthys olivacens*) and black rockfish (*Sebastes schlegeli*) was initiated in Korea during the latter part of the 1970s, with successful implementation achieved by the conclusion of 1980. In the 1990s, this industry flourished. Since the 1980s, grouper (*Epinephelus spp.*) cage culture has been performed in the Philippines. In the 1990s, milkfish were raised for mariculture, which fuelled the industry's continued expansion. Utilizing existing water sources for cage farming has minimal to no financial requirements. For a cage farm to operate effectively, particularly in terms of proper water quality inside the cage, minimal environmental damage outside the cage, and cage farm economic sustainability, choosing an appropriate site is essential. When determining a good place, it is important to consider the natural tolerance of the species.

4.2.1 Benefits of Cage Culture

1. Occupy a small area
2. Cage can be made by local and cheap materials
3. Anybody can manage small cage culture
4. Fish can be stocked with high density.
5. Yield and profit are high
6. Easy to harvest.
7. Could be an alternative income source for the local people

4.2.2 Site Selection for Cage Installation

The selection of the site for cage farming necessitates meticulous deliberation due to its impact on the economic viability of the farm. The selection of a suitable location is crucial in ensuring optimal water quality, which is essential for mitigating stress and facilitating the optimal growth of farmed fish. Additionally, it is imperative to ensure the proper and secure installation of cages, along with providing logistical support and help for input supply, fish harvesting, and fish selling. The geographical placement of the sea cage has a direct impact on various aspects of the business, including costs, fish mortality rates, production output, and overall profitability. During selecting a site for marine cage culture, it is essential to consider the following factors:

1. The cage site should be at an appropriate depth, have excellent circumstances for tidal flow, and ideally be shielded from strong winds and bad weather.
2. To restore oxygen inside the cages and to prevent waste from building up beneath the cages, good water exchange is crucial at cage farm locations. In situations when nature is used as a supplement to man-made food sources, sites with a slower water exchange rate may be desirable.
3. Because passing vessels' wakes can cause waves that can physically harm cage structures, cages should be situated away from navigation routes.
4. Industrial waste disposals, as well as municipal, industrial, and agricultural runoff, should not be present at cage locations.
5. In order to promote water exchange, prevent oxygen depletion, debris collection, and the buildup of some toxic gases caused by the decomposition of the deposited wastes, it is necessary to allow enough depth under the cage.
6. Because trash accumulation at the bottom is easily removed, cage culture sites with sloping slopes from the coast leading to flat bottoms are acceptable.
7. The cages' accessibility and the ability to remove them from potentially dangerous situations like algal blooms and/or low DO events should also be considered while choosing a site.
8. Locations with a high rate of fouling and frequent harmful algal blooms should be avoided.
9. Locations where pathogenic or potentially pathogenic organisms exist should be avoided before the farm is established.
10. Bays, straits, and inland seas provide excellent cage culture locations as long as they are shielded from strong winds and other inclement weather and have enough water circulation.

11. Temperature, pH, nitrogenous compounds, dissolved oxygen, and other aspects of the water quality in the cage locations should all be within the ideal ranges that support the growth and survivability of the cultured species.

12. Legal requirements, support staff and facilities, security, and management techniques are the final set of criteria that must be taken into consideration.

4.2.2.a Environmental Parameter for Site Selection

The selection of a site for cage culture is primarily determined by many environmental parameters, including depth, current, shelter, wind, wave, seabed, and water quality standards. The following factors play a crucial role in the decision-making process.

i. In order to accommodate large-scale commercial cage culture, it is recommended that the culture site possess a minimum depth of 6 meters. In the context of small-scale cage farming, the recommended dimensions typically range from 1 to 3 meters. It is imperative to ensure the segregation between the cage net bottom and the seafloor. It is advisable to promote the removal of metabolic and feed wastes that accumulate beneath the cage, optimize water exchange, and minimize oxygen depletion, among other considerations. The depth of a farming site has implications for various aspects such as the regular inspection of net and mooring lines, the design of mooring systems, and the determination of appropriate chain length, among other considerations. In this study the site's depth was deemed appropriate for the implementation of small-scale cage culture.

ii. An optimal seawater current velocity ranges from 0.5 to 1.0 m/s. The excessive velocity of the prevailing current exerts significant pressure on both mooring systems and cages, resulting in the mortality of cultivated fish. The speed of water currents has a significant impact on various aspects of aquatic systems, including water exchange, feed dispersion, net form and volume, solid waste dispersion, and efficient monitoring. The coastline area of St. Martin's Island has been recorded to exhibit a current velocity ranging from 0.5 to 0.7 m/s. The present velocity of the research region was deemed appropriate for the installation of cages.

iii. The establishment of a protected area is quite advantageous as it effectively safeguards enclosures from adverse weather conditions. Nevertheless, it is common for a substantial amount of waste to accumulate and pollute the seabed at the location of fish cages after extensive farming activities, as food waste and fecal matter tend to concentrate in these areas. Therefore, our research suggests that exposed and semi-exposed areas are best for sustainable farming over the long run.

iv. Wind is a significant factor in determining the height of the waves, and when the waves are high, it might be difficult to reach the fish cages and do routine operations such as feeding the fish, monitoring the cages, and other similar activities. In this study, we also took into account the conditions of the wind and the waves.

v. The characteristics of the seabed will play a role in determining the mooring method as well as the type of anchors that will be used. When it comes to anchoring, solid mud, clay, sand, and pebbles are all good options to consider. The ocean floor, which consists of rocks, corals, and stones, will need to be anchored by deadweight using gabions, which are mesh cages packed with various types of stones and other materials. Iron made anchor was used to tie the cage with the seabed in this study.

4.2.2.b Water Quality Criteria for Site Selection

In order to adequately address the biological requirements of the farmed species, it is imperative that the water quality at the cage site be of high standard. Some of these needs include the temperature, salinity, pH, dissolved oxygen, nutrient, and heavy metal levels that should be present within the suitable range. It is not acceptable for the water to have an excessive amount of suspended particles, a high frequency of algal blooms, or disease-causing organisms.

Table 4.1 The optimal water quality and tidal parameters for Cage Culture in the coastal waters (Prema, 2009)

S. No.	Environmental factors	Optimal range
1	Temperature (°C)	20-27
2	Salinity (ppt)	24-37
3	Dissolved oxygen (DO) (mg/L)	6 -7
4	pH	6.5-8.3
5	Electrical Conductivity (mS/m)	0.99 - 64.5
6	TDS (g/l.)	0.5 – 30

7	Optimum transparency (Secchidisk visibility) (m)	< 5
8	Nitrite (NO_2-N) (mg/L)	<0.1
9	Nitrate (NO_3-N) (mg /L)	0.2-5.0
10	Phosphate (PO4) (mg /L)	0.1-0.5
11	Silicate (SiO4) (mg /L)	0.1-10.0
12	Ammonium (mg /L)	0.01-0.4
13	Chromium (Cr) (mg/L)	< 0.05
14	Cadmium (Cd) (mg/L)	<0.05
15	Mercury (Hg) (ppm)	<0.05
16	Arsenic (As) (mg/L)	<0.0175
17	Lead (Pb)(mg/L)	<0.1
18	Copper (Cu) (mg/L)	0.05-0.1
19	Zinc (Zn) (mg/L)	<0.05
20	Turbidity (NTU)	<20

Source: Prema, 2009

The physical conditions, nutrients, and heavy metals required for cage farming vary on a number of variables, including the fish species, age, environment, and length of exposure. Based on the data that had been gathered, three distinct stations in the coastal sea near St. Martin's Island were selected for marine cage culture.

4.2.3 Construction of Cage

In cage aquaculture, cages can be several types-

i. Stationary cage
ii. Floating cage
iii. Submersible cage, and
iv. Submerged cage

In shallow water within1to 3 meters, the most common and widely used cage is the fixed cage. It consists of net bags on poles and is placed in moving water such as canals, rivers, rivulets, shallow lakes, and reservoirs. Although simple and cheap to construct, the usefulness of fixed cages is limited. On the other hand, the net bags kept in floating cages can dangle in the water without ever touching the bottom. Floating cages are commonly utilized in aquatic environments with a depth exceeding five meters. These kinds of cages have been manufactured in an enormous range of sizes, configurations, and styles so that they can be adapted to the broad spectrum of conditions that exist when fish are raised in open waters. The buoyancy of submersible cage net bags can be adjusted, and the bags can either be rigid or flexible. They are hung from the surface. Infrequently utilized are submerged net bags within a durable and resilient structure that is immersed in water. The materials utilized for the construction and installation of the cage encompass components such as an iron framework, floats, vacant plastic drums, anchors, and nylon netting, among others. In this study, fixed cage constructed by iron frame, floats, empty plastic drams, anchors, and nylon net, was used for cultivation of the selected species.

4.2.4 Selection of Suitable Species

Cage culture in the ocean necessitates a fish species that meets a number of criteria, including marketability, commercial significance, consumer acceptability, ease of culture, adaptability to the cage environment, acceptance of formula feeds, a faster development rate, and resistance to common diseases. The following criteria must be met when choosing a species for sea cage farming:

1. The species must have a strong market demand and high market value.

2. Farming should be cost-effective for the species.

3. Species should be able to withstand the stresses of handling during net cage adjustments as well as crowded, cramped environments.

4. In limited spaces, species should accept food from outside sources.

5. When choosing the species, it is important to take seed availability into account, whether it comes from wild harvest or hatchery products. Otherwise, farming becomes uncertain.

6. The species chosen for cage culture should have a quick rate of growth, good food conversion, and disease resistance.

Depending on the above criteria the leading fish species to cultivate in cage in Asia are follows:

Chanos Chanos (Milk Fish):

Advantages:

- Omnivorous/herbivorous.
- Pond and sea cages both see rapid growth (commercial size in 6 months)
- Wild fry are available.
- Tolerates significant salinity variations.
- Well-suited to polyculture.

Limitations:

- Primarily rely on wild fry.
- Fish with a moderate to low value.
- Limited to domestic markets

Lates calcarifer (Barramundi):

Advantages:

- Standardized seed production in hatcheries.
- Rapid growth (plate size in 4 months, 1 kg in 8 months).
- Appropriate for both cage and pond culture.
- Extremely high tolerance for changes in salinity and water quality
- The best species for raising fresh fish for local consumption.

Limitations:

- A high-protein diet is necessary.

Rachycentron canadum (Cobia):

Advantages:

• Usually produced regularly in hatcheries.

• Very rapid expansion (6–7 kg in year).

• Appropriate for high-density cage culture and simple to maintain.

• Suitable for the large production of fresh or frozen white fillets.

• Growing out has a high survival rate, and achieving an average survival rate of 90% is not difficult.

Limitations:

• High protein requirements yet a respectable FCR (<2).

• Relatively large manufacturing units, low temperatures, and high-quality water are required.

• Sensitive to illnesses, particularly in water of lesser quality.

• Fresh domestic fish markets and export markets for whole fish do not have extremely high values.

S. lalandi and S. rivoliana (Amberjack):

Advantages:

• Rapid growth (2 kg in 12 months).

• Appropriate for high-volume hatchery production.

• Exorbitant retail costs.

• Fits the sashimi market for fresh fish.

• Appropriate for both the domestic market and export

Limitations:

• Brood stock can be difficult to locate and is generally unknown.

• High lipid, generally extremely high lipid, and FCR (>2) requirements.

• Parasite sensitivity

Siganus spp (Rabbit fish)

Advantages:

• Omnivorous/herbivorous.

• Moderate growth (commercial plate size in 9–12 months).

• Well-suited for cage culture and tolerant of dense stocking.

• Some species can withstand changes in the water's quality.

• Exorbitant costs in some places.

• Appropriate for aquaculture based on capture (CBA).

Limitations:

• Not all species' hatcheries have reached their full potential for output.

• Its poisonous spines make handling during cultivation and harvest difficult.

• In some regions, value is average.

• Recognized for damaging net cages by grazing on them.

Lutjanus argentimaculatus (Snappers),

Advantages:

• Useful if the fish is red in color.

• Appropriate for cage culture.

• Accepts low salinity.

• Tolerant of changes in water quality.

• Common in regions with estuary systems.

Limitations:

Mangrove jacks raised in captivity are often gray in color (lower value).

• A high requirement for protein.

• Slow expansion.

• The market value is average.

Lutjanus sebae / L. Johnii (Red Emperor/John's Snapper)

Advantages:

• Fish with a high value for both the domestic and fresh export markets.

• Appropriate for cage culture.

Limitations

• The efficacy of routine hatchery production has not yet been empirically established, but it has been demonstrated for specific species within the same genus.

• A high requirement for protein.

Epinephelus spp. (Groupers):

Advantages:

• For a few species of grouper, hatchery procedures have been standardized.

• Appropriate for pond and cage culture.

• Can come from shrimp farms as a byproduct.

• High pricing in the market for live fish.

• Medium-sized fish are easier to manage than larger species because of their high values on most domestic and international markets (plate size in 9-12 months).

Limitations:

• Require diets high in protein.

• High levels of cannibalism during the early nursery and late larval rearing phases.

• Southeast Asia and other export markets are highly competitive.

Trachinotus blochii (Asian or silver Pompano):

•High retail price,

• Suitability for intensive hatchery production,

• Optimal growth,

• Ease of adaptation to a variety of salinity levels, and

• Suitability for artificial diets.

Limitations:

• Demand for high-protein diets.

Mugil spp. (Mullet):

Advantages:

• Wild-caught fry is accessible.

• If juveniles are available, a good contender for family food security in densely crowded places.

• Acceptable for water quality.

• Appropriate for pond and cage farming.

Limitations:

• No export value.

• Low value in most markets for fresh fish.

• A number of locations have not yet standardized hatchery production.

Other species:

A broad variety of additional species, such as threadfins, croakers, drums, gobies, scorpion fish, and others, are cultured in addition to the aforementioned species. Numerous of these species are at least sporadically produced in marine cages. Therefore, while choosing species for cage culture operations, the aforementioned traits should be carefully considered and given the utmost weight. Some of these characters might be more significant in particular regions, and as a result, it is imperative to accord higher attention to those characters within the specified regions to optimize economic benefits and ensure the sustainability of the cultural system. John's Snapper (*Lutjanus johnii*) a carnivorous fish, was chosen for marine cage farming in this study.

4.2.5 Collection of Fingerlings

For cage-based grow-out cultures to be successful, fish seed quality is essential. It is best to plant uniform-sized seeds that correspond to the mesh size of the fish net cage to stop them from escaping. Additionally, this will help choose the appropriate fish meal size, reduce cannibalism, and prevent feed waste. Seeds must be healthy, disease-free, and free from defects. Typically, farmers gather fingerlings from hatchery or the wild. Seedlings are gathered from natural sources for this investigation.

4.2.6 Feeding Behavior

The consideration of feeding rates, feeding frequency, and feeding length holds significant importance in the context of cage farming. The quantity and frequency of feeding are influenced by the age and size of the fish. Fish larvae and fry sometimes necessitate more frequent feedings of a diet that is rich in protein. There is a possibility that larger fish exhibit reduced feeding frequencies and rates. The labor-intensive nature of fish feeding necessitates a reevaluation of the feeding frequency to optimize profitability. Typically, an increase in feeding frequency is associated with an elevation in both growth rate and feed conversion efficiency. Several variables, including temporal elements such as the time of day and season, as well as physical parameters like water temperature, dissolved oxygen levels, and other aspects of water quality, have an impact on the feeding behavior of organisms. In this research, trash fish was used as the only supplementary feed to reduce the cost of cultivation.

4.2.7 Fish Harvesting

Fish can be harvested after 4-6 months of cultivation. Scoop net could be used for partial harvesting of fish from the net cages. For harvesting all the fishes, if the cage is small enough the whole cage could be pulled into shallow water and fish could be collected by small hand net. Scoop net was used to harvest fish in this study.

4.3 Seaweed Culture

Seaweed culture, also known as seaweed farming, is the process of cultivating and harvesting seaweed in controlled environments for various purposes, such as food, medicine, cosmetics, and biofuel production. Seaweeds, also called marine macroalgae, are multicellular marine plants that grow in the shallow coastal waters and can be found in different colors, shapes, and sizes. Seaweed mariculture is thought to have begun during the Tokugawa Period (AD 1600–1868) in Japan. The low-lying country of Bangladesh is located in South Asia between latitudes 24°34' and 26°38' North and longitudes 88°01' and 92°41' East. Overall, there are 147,570 square kilometres (56,977 sq. miles). Bangladesh, situated inside the Indo-Burma biodiversity hotspot, occupies a transitional region for the plant and animal species found in the Indian subcontinent and Southeast Asia. The coastline region of Bangladesh, spanning 710 kilometers in length and encompassing an area of 25,000 square kilometers, facilitates a diverse array of land use patterns. According to specialists, this coastal region's estuaries, mangrove swamps, and sandy and muddy shores offer foundations and ecosystems for the production of several species of seaweed (Siddiqui et al., 2019). Currently, the global seaweed supply is predominantly sourced from cultivated species, accounting for 92% of the total supply. The coastal region of Bangladesh provides a suitable substrate and habitats for the production of several seaweeds, along with mangrove swamps, estuaries, muddy and sandy beaches. There are 133 varieties of seaweed in Bangladesh, 14 of which are prominent economically (Siddiqui et al., 2019). In several south-east Asian nations, seaweed cultivation is well advanced. Additionally, the biochemical, pharmaceutical, and cosmetics industries use seaweed as a constituent. However, Bangladesh's seaweed sector is still in its infancy. If carefully cultivated and investigated, seaweed might become a crucial agricultural commodity for coastal areas, be utilized in food preparation, be employed in the pharmaceutical and cosmetics sectors, and boost the country's economy. In Inani Beach, Cox's Bazar, St. Martin's Island, and the Sundarbans, seaweed existed in great abundance. It has the potential to thrive on many substrates such as rocks, permeable sediments, stones, and even other species of marine algae. The sea is a special resource. There are resources with numerous potential applications. One such priceless gift from the sea is seaweed. According to legend, the first seaweed was grown in Tokyo, Japan, around 1670. In 1940, it first experienced commercial cultivation. Along with Japan, several other Asian nations, including the Philippines, Vietnam, and Thailand, began producing it. Iodine, a variety of vitamins, and minerals are all abundant in seaweed. In Bangladesh Seaweed farming is a crucial sector that has grown near the Cox's Bazar airport on the shore of Nuniyachhara of the Maheshkhali channel in very small quantities.

4.3.1 Benefits of Seaweed Culture

Seaweed culture could play a very important role for promoting blue economy of a country. The seaweed industry sectors targeted as part of the blue economy initiatives consist of-

- Food production (Agar, carrageenan, soup, ice-cream, sweets, salad, jam)
- Pharmaceuticals (Alginate, medicines, Ointment, dental product)
- Hair cream, cosmetics, shampoo, shower gel
- Textile printing
- Ceramic

- Poultry feed
- Fertilizer
- Paper and paint and
- Biofuel

4.3.2 Seaweed and it's Type

Seaweed, often known as macroalgae, is a diverse group of multicellular marine algae that includes a wide range of unique species are commonly observed thriving in coastal areas. Seaweeds exhibit a diverse range of morphological characteristics, encompassing various shapes, sizes, colors, and chemical compositions. In contrast, seaweeds, also known as marine macroalgae, are organisms with plant-like characteristics that commonly inhabit coastal environments, typically attaching themselves to rocks or other firm sedimentary substrates (Kılınç et al., 2013). Seaweeds exhibit a wide distribution across many habitats, encompassing rocky shorelines, sandy beaches, and muddy bottoms. A wide variety of seaweed species can be observed thriving in the world's oceans and seas. However, extensive research conducted by Bold & Wyne (1985), Soler-Vila (2009) and Lobban & Harrison (1994) has shown no evidence of any of these seaweed varieties posing harm to human beings. Seaweed plays a crucial role in the food webs that sustain marine and aquatic ecosystems. Bernays & Chapman, (1970) assert that they represent a plentiful reservoir of a substance that finds extensive application in the cosmetics and pharmaceutical sectors, alongside minerals and noteworthy trace elements. Humans have been consuming seaweed and used it for medical purposes for over 14,000 years. The growth of the aquaculture sector, particularly in Asia, has been significantly influenced by the rising need for edible seaweed and its bioactive metabolites, such as agar, alginate, and carrageenan, which are commonly used in refined goods (Buchholz et al., 2012). The aforementioned demand has exerted significant influence, notably throughout the Asian region. The nomenclature encompasses certain species of macroalgae belonging to three divisions-

i. Rhodophyta (Red Algae),

ii. Chlorophyta (Green Algae), and

iii. Phaeophyta (Brown Algae)

Various species, particularly unicellular algae, perform a vital function in the sequestration of carbon, contributing significantly to the overall production of oxygen on Earth. Seaweed species, such as kelp, provide a crucial nursery habitat for fisheries and other marine organisms, hence safeguarding food resources.

4.3.2.a Rhodophyta

The origin of red algae remains an enigma. Historically, the Rhodophyta were once classified as plants until being recognized as the earliest eukaryotic organisms. According to Stiller & Hall (1997), recent genetic studies have revealed shared characteristics between red and green chloroplasts, suggesting that these organelles may have evolved from a single endosymbiotic event in a common ancestor of both rhodophytes and green plants. Moreover, the Rhodophyta phylum is considered to be one of the largest groups of algae, encompassing more than 7,000 species that have been identified thus far, with ongoing taxonomic revisions being conducted (Brodie et al., 2016). Red algae constitute a distinct group characterized by the absence of centrioles and cilia in their eukaryotic cells, unstacked (stroma) thylakoids in their chloroplasts without external endoplasmic reticulum, and the utilization of phycobiliproteins as pigment molecules, which impart their red coloration (Campbell & Woelkerling, 1990).

Figure 4.1 Red algae (Gracilaria Sp.)

4.3.2.b Chlorophyta

The taxonomic designation for the group of green algae commonly referred to as chlorophytes is Chlorophyta or Prasinophyta, as stated by Rockwell et al., 2017. The group of green algae, comprising chlorophytes, charophytes, and embryophytes, possesses both chlorophyll a and b, and stores energy in the form of starch within their plastids, similar to land plants (Hoek et al., 1995). According to Lee (2018), almost 90% of the documented plant species are found in freshwater environments. According to Umen (2014), the majority of Chlorophyta lineages are composed of unicellular organisms, with the exception of Palmophyllophyceae, Trebouxiophyceae, Ulvophyceae, and Chlorophyceae, which display different levels of multicellularity. Certain members of the group engage in symbiotic interactions with sponges, cnidarians, and protozoa. A diverse array of fauna exists in a state of unrestricted liberty, whilst certain organisms engage in symbiotic relationships with fungi to create lichens. According to Kapraun (2007), all members of the group possess motile flagellar swimming cells.

Figure 4.2 Green Algae (Ulva sps)

4.3.2.c Phaeophyta

Brown algae are the prevailing seaweed species found in both polar and temperate zones. In regions characterized by cooler climates, these organisms exhibit a dominant presence along rocky coastlines. The predominant occurrence of brown algae is observed in marine environments, where they serve as significant sources of sustenance and potential abodes. An example of a kelp species that belongs to the order Laminariales is Macrocystis. This particular species has the potential to reach a length of 60 meters (200 feet) and is responsible for the formation of prominent kelp forests under the water's surface. According to Hoek (1995), the number of distinct brown algae species ranges from 1,500 to 2,000. Brown algae from different families have considerably larger sizes. According to Dittmer (1964), rockweeds and leathery kelps are frequently observed algae in their immediate environment. The brown algae encompass the largest and most rapidly expanding seaweeds (Connor & Baxter, 1989).

Figure 4.3 Brown algae (Padina sp).

4.3.3 Nutritional Composition of Edible Seaweeds

Seaweed is a nutrient-dense food that is high in vitamins, minerals, and other beneficial compounds while being low in calories. Seaweed is an excellent source of iodine, which is essential for thyroid health and metabolism. Vitamins A, C, E, and K are abundant in seaweed, as well as B vitamins like folate and niacin. Seaweed contains calcium, magnesium, iron, potassium, and trace minerals such as zinc and selenium. Seaweed contains a lot of fiber, which can help regulate digestion and make you feel full. It contains antioxidants such as carotenoids, flavonoids, and phenolic compounds, which may aid in the prevention of oxidative stress and inflammation. Five brown and two red edible Spanish seaweeds-were examined for their proximate composition (condensation, soot, nutrients, and aromatic oils), ideal fiber content, and physicochemical properties. The presence of ashes was observed in a significant proportion across all samples, ranging from 24.9% to 36.4%. The seaweed species *Laminaria* exhibited the highest protein level, measuring at 25.7%. Following *Laminaria*, red seaweed displayed protein contents ranging from 15.5% to 21.3%, with a minimum of 10.9% and a maximum of 25.7%. With the exception of *Bifurcaria,* all the samples analyzed contained minimal quantities of lipids, ranging from 0.3% to 0.9%. The value under consideration is 5.6 percent. In conclusion, it can be asserted that these seaweeds provide a substantial abundance of nutrients, protein, and fibre that can be utilized for human consumption (Gómez-Ordóñez et al., 2010). A variety of edible marine sea vegetables, namely *Laminaria digitata, Fucus vesiculosus, Chondrus crispus, and Undaria pinnatifida* were subjected to mineral content analysis. Seaweed samples were observed to exhibit elevated levels of ash content, ranging from 21.1% to 39.3%. Additionally, sulphate concentrations were detected within the range of 1.3% to

5.9%. The ash concentration exhibited higher values in brown algae (30.1-39.3%) compared to red algae (20.6-21.1%). To fulfil the suggested daily requirement of vital minerals and trace elements, one can consider integrating edible brown and red seaweed into their dietary regimen as an additional source (Rupérez, 2002). In this study, we want to compare the fatty acid profile, essential amino acid composition, protein score, mineral content, and antioxidant capabilities of sea spaghetti, Wakame, and Nori within reduced meat emulsion model systems. The introduction of seaweeds into the experimental system led to a notable elevation in polyunsaturated fatty acid-3 (PUFA-3) levels, accompanied by a concurrent decrease in the ratio of polyunsaturated fatty acid-6 (PUFA-6) to PUFA-3. Overall, the levels of calcium (Ca), potassium (K), manganese (Mn) and magnesium (Mg) exhibited an increase when seaweed was incorporated into the products. According to López-López et al. (2009), the amino acid compositions in the model systems were not significantly altered by Wakame and Sea Spaghetti. However, the inclusion of Nori resulted in elevated amounts of serotonin, glycine, alanine, phenylalanine, tyrosine, and arginine. The study conducted by Dawczynski et al. (2007) examined various seaweed species and found that all of them contained the necessary amino acids. Additionally, the research revealed that red algae species exhibited much higher levels of taurine compared to their brown algal counterparts. Both types of seaweeds provide a balanced supply of omega-3 and omega-6 fatty acids. The red seaweeds are primarily composed of saturated fatty acids, whereas the brown seaweeds analyzed contain predominantly unprocessed fatty acids. According to Sánchez-Machado et al. (2004), the ash content ranged from 19.07 ± 0.61 to 34.00 ± 0.11 g per 100 g of dry weight, whereas the protein content ranged from 5.46 ± 0.16 to 24.11 ± 1.03 g per 100 g of dry mass.

4.3.4 The utilization of seaweed in the culinary domain

Red macroalgae, specifically *Gracilaria spp*., are commonly ingested as a fresh dietary option in the state of Hawaii. The species that are frequently available for sale are *G. parvispora, G. coronopifolia, G. tikvahiae,* and *G. salicornia.* However, it is worth noting that their postharvest lifespan is typically limited to approximately four days Chen et al. (2008). Seaweed possesses a substantial quantity of phytochemicals that have antioxidant and antibacterial properties. The addition of minerals and fibers to a substance results in an increase in mineral content and a decrease in salt concentration. According to Gupta & Abu-Ghannam (2011), the incorporation of seaweeds or their extracts in food products can be beneficial in reducing the reliance on synthetic additives. According to Fernández-Martín et al. (2009), alginates appear to be the most prevalent ionic polysaccharide in brown seaweeds. Several seaweed polysaccharides are utilized as texture modifiers in the food industry owing to their notable fluidity and gelatinization properties. Seaweeds have been traditionally included into culinary practices in Asia, where they are commonly utilized in the preparation of salads, soups, and low-calorie dietetic meals. Dietary fiber, including around 25-75% of the dry weight of algae species and serving as a major constituent, is primarily regarded as an economically feasible fiber (Jiménez-Escrig & Sánchez-Muniz, 2000). According to Song et al. (2012), the lyophilized and blasted miyeokguk, exposed to a dose of 10 kGy of gamma radiation, meets the microbiological standards required for space food. The radiation intensity at hand is deemed enough for the purpose of sterilizing freeze-dried miyeokguk, while having minimal impact on its sensory characteristics.. The presence of carrageenan at a concentration of 3 percent resulted in a negative effect on the rigidity of the sausages. According to Koutsopoulos et al. (2008), the use of carrageenan in low-fat foods, at concentrations of up to 2%, was found to enhance their chemical and microbiological characteristics. Bread products with Lemna minor exhibited an acceptable duration of freshness on the eighth day when stored at ambient temperature, although failed to maintain satisfactory quality on the twelfth day when stored at 4 °C. Nevertheless, the control group surpassed the established threshold on days 3 and 8 under two different temperature conditions: 4 degrees Celsius and room temperature, respectively (Turan et al., 2011).

4.3.5 Production of Biogas and Fertilizer from Seaweeds

According to López-Mosquera et al. (2011), the utilization of seaweed as a fertilizer renders it suitable for organic farming. The process of anaerobic digestion of seaweed deposits has the potential to generate methane with a significant energy content. The utilization of seaweed and its digestates as fertilizers is hindered by their substantial concentration of heavy metals. The utilization of seaweed in an efficient manner for the production of biogas, as well as the controlled release of heavy metals to facilitate their subsequent removal, has been explored by Nkemka & Murto (2012). In the study conducted by Pacheco-Ruíz et al. (2004), the cultivation of *Chondracanthus squarrulosus*, a type of red seaweed, was carried out under semi-controlled conditions. The purpose of this cultivation was to assess and compare the growth of the algae in relation to several factors, including the use of analytical grade inorganic salts, agricultural runoff, and saltwater, which were employed as control variables.

4.3.6 Impacts of Seaweed Culture on the Environment and the Ecosystem

The production of seaweed possesses the capacity to give rise to a range of environmental concerns. Seaweed cultivators occasionally remove mangroves in order to utilize the wood as pegs for their rope production. Nevertheless, the aforementioned practice has adverse effects on agricultural activities since it leads to the depletion of biodiversity within mangrove ecosystems and a subsequent decline in water quality. In certain instances, it may be necessary to undertake the removal of eelgrass from agricultural regions. Nevertheless, engaging in such activities is strongly discouraged due to its detrimental effects on water quality (Hatziolos et al., 1998). Seaweed farming has a role in the maintenance of coral reefs (Zertuche-González, 1999). By increasing the diversity of transplantation methods for seaweed and algae, it also provides indigenous fish and invertebrate species with additional ecological niches to occupy. According to Ask and E.I (1999), the practice of farming can yield benefits by facilitating the proliferation of plant-eating shellfish and fish populations. Furthermore, the process of seaweed cultivation allows for the capture, absorption, and subsequent incorporation of additional nutrients into living tissue. The term commonly employed to refer to the process of bioremediation utilizing grown plants and animals is "nutrient bioextraction." The practice of cultivating and collecting shellfish and seaweed for the purpose of nutrient bioextraction, commonly referred to as bio-harvesting, is employed to extract nitrogen and various other elements from natural aquatic environments (Rose et al., 2014). There has been significant scholarly attention directed towards the inquiry of the potential efficacy of open water seaweed farming as a means of carbon sequestration to mitigate the effects of climate change (Broberg et al. 2021; Krause-Jensen, 2017). In addition, there is no other organism on the planet that exhibits a higher rate of carbon sequestration than *Macrocystis pyrifera*, commonly referred to as giant kelp. This species has the potential to reach lengths of up to 60 meters and can grow at a remarkable pace of 50 centimetres per day under ideal conditions (Schiel & Foster, 2015). Hence, a hypothesis has been put up suggesting that the production of seaweed on a large scale could have a substantial impact on climate change. According to a recent estimate, around 9% of the global marine areas are occupied by kelp forests. This finding suggests that harnessing the potential of these kelp forests may potentially generate sufficient biodiesel to meet the current global demand for fossil energy. Moreover, this use might also lead to a significant reduction of approximately 53 billion tonnes of carbon dioxide emissions annually, thereby mitigating the adverse environmental impacts associated with previous conditions (Antoine de Ramon et al. 2012). Seaweed cultivation could potentially serve as a first measure for adapting to forthcoming environmental constraints resulting from climate change, in conjunction with efforts aimed at mitigating climate change impacts. One important factor to consider for coastal safety is the dispersion of wave energy in mangrove beaches. The consumption of carbon dioxide would result in a localized decrease in pH, which might provide significant benefits to calcifying organisms such as crustaceans or potentially prevent the occurrence of irreversible coral bleaching. The implementation of seaweed cultivation and restorative ocean husbandry practices would yield a substantial augmentation in the oxygen levels within coastal waters. This, in turn, would serve as a mitigating measure against the adverse effects of ocean deoxygenation resulting from the rise in oceanic temperatures (Krause-Jensen, 2017; Steppe, 2021).

4.3.7 Global Seaweed Culture Status

The current state of seaweed cultivation on a global scale is subject to ongoing fluctuations. Based on a report published by the Food and Agriculture Organization (FAO), the global output of seaweed in the year 2018 amounted to 30.4 million tonnes, yielding a total economic worth of US$10 billion. Projections suggest that this value has the potential to escalate to US$26 billion within the next decade. The majority of production is concentrated in Asia, with China, Indonesia, and the Republic of Korea emerging as the leading producers. The number of seaweed species exceeds 10,000; however, only a limited selection is typically farmed for commercial applications. The cultivation of brown seaweeds, including kelp, and red seaweeds, such as nori and dulse, is prevalent in the aquaculture industry. Conversely, the cultivation of green seaweeds is comparatively less widespread. Seaweed cultivation can be achieved by the utilization of hanging ropes, nets, or other structures in the marine environment, as well as by cultivating it directly on the ocean floor. The predominant approach involves cultivating seaweed on hanging ropes or nets, which can be positioned at varying depths within the aquatic environment. In general, there is a growing global trend towards the expansion of seaweed cultivation, driven by a rising enthusiasm for the establishment of environmentally sustainable methods in seaweed farming. The anticipated growth of the seaweed sector is expected to be driven by the increasing demand for seaweed products. This expansion is particularly likely to occur in Asia, which now accounts for the majority of seaweed production.

4.3.8 Criteria of Suitable Site Selection for Seaweed Cultivation

The subsequent guidelines outline the process of finding appropriate locations for seaweed cultivation-

- **i.** At high tide, the cultural site must be between one and three meters deep. The distance between the long line and the seafloor should be at least one meter. The net for the net method must be 1 m above the ocean floor because if the test plants or seedlings can't float, the results won't be visible. The depth of the area chosen for this study was 1.0 m.
- **ii.** The optimal range for seaweed culture is often characterized by saltwater current speeds ranging from 0.5 to 1.0 m/s. In the event that the current flow exceeds a certain threshold, it might result in the displacement and subsequent breakage of seedlings from their designated cultural site. Due to this rationale, the culture site will not yield any output. In the context of seaweed cultivation, it is imperative to avoid harsh settings and extremely intertidal zones. The study area exhibited a range of seawater current speeds between 0.5 and 1.0 m/s.
- **iii.** Wind-driven high waves make it challenging to access cultural sites and do daily tasks like nursing and seaweed harvesting. This complicates the cultivation and harvesting of seaweed, which has an adverse effect on its usefulness for economic purposes. The place chosen for this research made use of both favorable winds and waves.
- **iv.** The establishment of a suitable bottom is crucial for the cultivation of seaweed. The majority of commercially significant seaweed species thrive in aquatic environments characterized by water flow or floating conditions. When the seabed experiences excessive turbidity, it has an impact on the growth and development of seedlings. As a consequence, the level of net harvesting is disturbed. Seaweed requires a consistent and unobstructed water flow that allows for transparency. The qualities of a lagoon are interconnected, and as a result, the successful harvesting and net yield are dependent on the presence of a reef that forms the seabed, characterized by clear saltwater. The chosen location in this study exhibited favorable conditions for seabed formation, as indicated by the turbidity levels falling within the acceptable range of less than 10 NTU.

4.3.9 Water Parameters for Site Selection

At the cultivation site suitable range of the water's dissolved oxygen (DO), temperature, pH, salinity, transparency, alkalinity, nutrient, heavy metal concentration and other important water criteria are required. Ensuring optimal water quality is of paramount significance in seaweed culture systems, including adequate water flow, oxygen levels, and nutrient balance, to prevent the build-up of toxic compounds. Regular water testing and monitoring can help ensure optimal conditions for healthy seaweed growth.

Table 4.2 The optimal water quality and tidal parameters for Seaweed Culture in the coastal waters (McHugh, 2003)

S. No.	Environmental factors	Optimal range
1	Temperature (°C)	15-27
2	Salinity (ppt)	25-35
3	Dissolved oxygen (DO) (mg/L)	5 -7
4	pH	7.5-8.5
5	Electrical Conductivity (mS/m)	0.99 - 64.5
6	TDS (g/l.)	0.5 - 30
7	Optimum transparency (Secchidisk visibility) (m)	< 5
8	Nitrite (NO_2-N) (mg/L)	<0.1
9	Nitrate (NO_3-N) (mg /L)	0.2-5.0
10	Phosphate (PO4) (mg /L)	0.1-0.5
11	Silicate (SiO4) (mg /L)	0.1-10.0
12	Ammonium (mg /L)	0.01-0.4
13	Mercury (Hg) (mg/L)	<0.05
14	Arsenic (As) (mg/L)	<0.001
15	Lead (Pb)(ppm) (mg/L)	<0.1
16	Cadmium (Cd) (mg/L)	<0.5
17	Chromium (Cr) (mg/L)	<0.5
18	Copper (Cu) (mg/L)	0.003-0.1
19	Zinc (Zn) (mg/L)	0.05-0.5
20	Turbidity (NTU)	<10

Source: McHugh, 2003

The physical parameters, nutrients and heavy metals that is necessary for seaweed cultivation depends on several factors such as the species of seaweed, the age of the seaweed, the environmental conditions, and the duration of exposure. For the purposes of this investigation, a specific station located in the coastal water near St. Martin's Island was chosen based on the available data.

4.3.10 Seaweed Selection and Seedlings Collection

Depending on all the physicochemical properties of the water, nutrient distribution, heavy metal distribution, commercial importance and availability of the species of seaweed should be selected. Coastal areas are great source for collecting seaweed species. After collecting the seeds, it should be immediately transfer to the culture site or preserve in the aquarium with continuous flow of marine water until transfer to cultivation site. In this study seaweed seedlings were collected from the coastal area near Rezu khal, Cox's Bazar.

4.3.11 Culture Method

Culture method is very important for the success of seaweed culture. There are two important methods of seaweed culture which are given below-

1. Long Line method
2. Floating Net Method

4.3.11.a Long Line Method

It has been proven that long line systems work well in areas with water depths of between one and five meters. It is standard practice in the context of large-scale commercial seaweed production to allot between 300 and 450 seedlings per line, with the precise amount depending on the size of each individual seed. By using this technology, manufacturing costs are lower than they would be using alternative methods. Every seedling should be attached to the rope using bobbin thread. Each seedling in a rope should be spaced 5 to 10 inches apart. Each line should be spaced roughly 2 to 3 feet apart. The line should be floated by fishing buoys that are attached.

Figure 4.4 Long Line Method

4.3.11.b Floating Net Method

This culture method typically employs a 2.5 m in diameter by 5 m long nylon or polyethelene net with a mesh size of 60 cm stretch for industrial seaweed growing. The planting unit used in the all-encompassing global strategy is a rectangular net measuring 2.5 x 5 m that has a diagonal hexagonal lattice with 25 cm-diameter bars. Nylon rope or stranded polyethylene wires with a test strength of 110 to 150 lbs. are used to make the net. On the other hand, lines with a test strength ranging from 30 to 100 lbs. are used to build the meshwork. A horizontal orientation is used to install the netting. The loop's corners are fastened to upright poles or wire that hangs between the stakes. By allowing for the cultivation of more plants in a given spatial area, net farming approach has the advantage of increased productivity.

Figure 4.5 Floating Net Method

In this study, seaweed was grown using both the Long Line and Floating Net methods, and all applicable guidelines were followed.

4.3.12 Planting

The seedling should be carefully cleaned before planting by getting rid of any dirt, epiphytes, and other items that attach to the plant. Prepared seedlings should plant right away. Seedlings (80–100 g) should be connected to each net intersection when using the net method. About 150 plants can fit in the original net. The bottom monoline method involves the planting of seedlings, which typically weigh between 50 and 150 grams. These seedlings are affixed to the monoline by means of a one-inch (2.5 cm) allowance of the nylon line's knotted portion. Seedlings should be spaced apart by 5-8 inches (20–25 cm). Planting technique was also followed in this study.

4.3.13 Harvesting

Seaweed can be harvested when it weighs between 750 and 850 g. The process of harvesting can be incorporated into the process of maintaining the area if the harvestable plants are first pruned and then allowed to regenerate.

4.3.13.a Harvesting Procedures

Pruning is the method of plant harvest by walking the area row by row. The branches of each plant should be chopped off using a stainless-steel knife. Leave each plant with about 200 g for regrowth.

i. When doing a complete plant harvest, it is recommended to sever the allowance section of the knot that secures the plant to the nylon line.
ii. Using scoop nets to gather harvested plants.
iii. Put all the gathered plants in the banca.
iv. Transport the banca to the designated drying location once reaching its maximum capacity.
v. Weigh all of the harvests before spreading them out to dry, and keep a record of the results.

Proper harvesting technique was also followed in the study.

4.3.13.b Drying

Guidelines for drying the gathered plants:

i. The seaweed that has been collected should be evenly distributed on the designated platform or drying area that has been specifically arranged for the purpose of drying the harvested plants.
ii. When drying on land, use coconut palms as flooring. To prevent contamination, never dry seaweed directly on or into the ground.
iii. In a drying platform, there should be roughly 2 lbs/sq ft of wet seaweed.
iv. For three days, rotate the seaweeds under the sun at regular intervals while also removing foreign objects. Seaweeds can only be dried for 1-2 days in the summer.
v. To protect the harvest from the rain, always cover it.
vi. Sort dried produce into groups based on the day it was picked.
vii. Seaweeds are deemed dry when their surface is devoid of any moisture or sand particles. They feel rubbery and are crunchy.
viii. Use mesh screens to sieve the dried seaweeds to remove salt flecks.
ix. Fill big sacks with clean, dried seaweed that hasn't been exposed to salt.
x. When selling the seaweeds, keep track of their total weight.

During the course of the research, the drying process was also carried out.

Chapter 5 **Research Methodology**

The research approaches used in this study are described in this chapter. The standard protocols used in this research are sample collection, storage, processing, analysis, cost benefit analysis, and so forth. The success of a scientific study is dependent on its methodology, which is a crucial and vital component of the research process. As a result, great thought must be paid to organizing technique in order to make the study systematic. A sound approach aids researchers in gathering accurate data for making informed conclusions. The methodologies and practices used to carry out this study have been detailed in this Chapter and are shown in the sections and subsections are given below.

St. Martin’s Island was taken as the pilot area to study the feasibility, and suitability of mariculture with a focus on identifying the ideal time of year, location, and fish and seaweed species to farm there. Seaweeds and other plants and animals, as well as other creatures, find a significant biological environment to live on St. Martin's Island. Despite being relatively under-researched, cage culture and commercially significant seaweed culture are not included in the research so far. Given the location's relative distance from Bangladesh's main island, cage and seaweed culture, which is commercially significant, has numerous difficulties as well. The comprehensive understanding of the optimal time of year, the most suitable site in terms of physicochemical properties of the water, the abundance of plankton, the distribution of nutrients and heavy metals, the cultivation technique, and the perfect species for aquaculture remains limited in knowledge on this particular island. In addition to improving the economic position of the area's unemployed, mariculture can play an important role in solving the issue. Conducting an analysis of the current situation on St. Martin's Island is necessary in order to determine the state of mariculture and its potential for promoting the blue economy in that region. In order to reach the study objectives, analysis of the physicochemical properties of the coastal water, determination of the spatial distribution of nutrients and heavy metal and investigations of the abundance, distribution, and diversity of phytoplankton and zooplankton in different seasons are required. We may determine the location, season, and species of fish that can be grown in the coastal waters of St. Martin's Island by looking at the physicochemical properties and distribution of phytoplankton and zooplankton, as well as the spatial distribution of nutrients and heavy metals. The physicochemical qualities and spatial distribution of nutrients and heavy metals in the coastal waters of St. Martin's Island may also help us to decide the location, season, and type of seaweed that can be farmed there. The acquisition of data pertaining to the physicochemical characteristics of coastal waters, the concentration of nutrients and heavy metals in the water, as well as the abundance, spatial distribution, and diversity of planktonic organisms over the course of a year, is estimated to require a minimum duration of three years. The workflow is as follows-

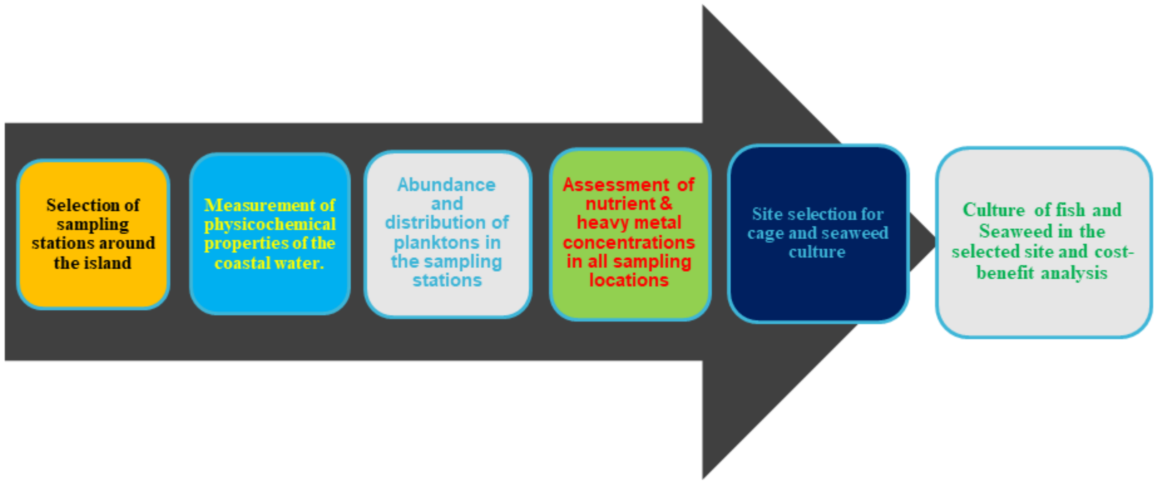


Figure 5.1: Workflow for achieving the goal

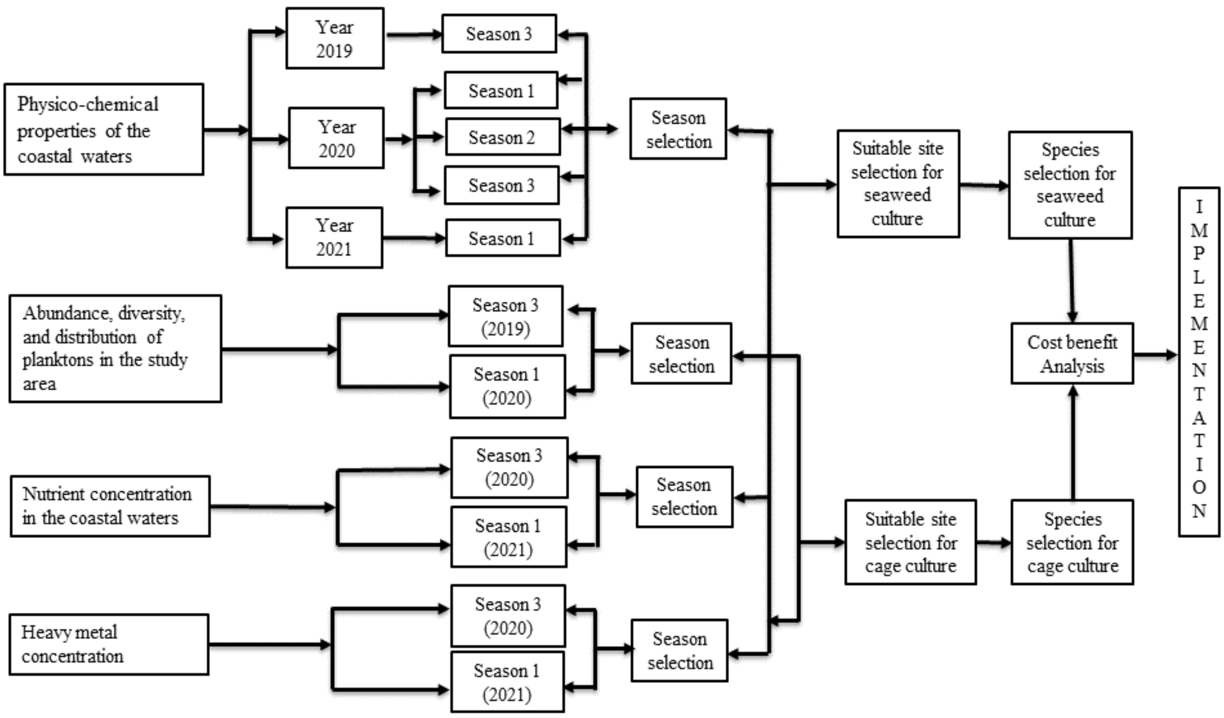


Figure 5.2: A Framework/Base work to determine the possibility of mariculture to promote blue economy of the St. Martin's Island

5.1 Materials and Methods

5.1.1 Study Area

The water samples were collected from the twenty-four sampling points from the coastal area adjacent to St. Martin Island. The first twenty-four points were randomly selected to narrow down the station numbers depending on the gathered data. After the collection, physicochemical parameters were measured using the digital instrument. The instruments that were used were all numeral and are fairly accurate. During the study, the physicochemical parameters i.e., temperature, pH, dissolved oxygen (DO), salinity, TDS, conductivity, nitrate, and phosphate of the coastal waters were recorded. Longitude and latitude of the randomly selected 24 points are given in Table 5.1.

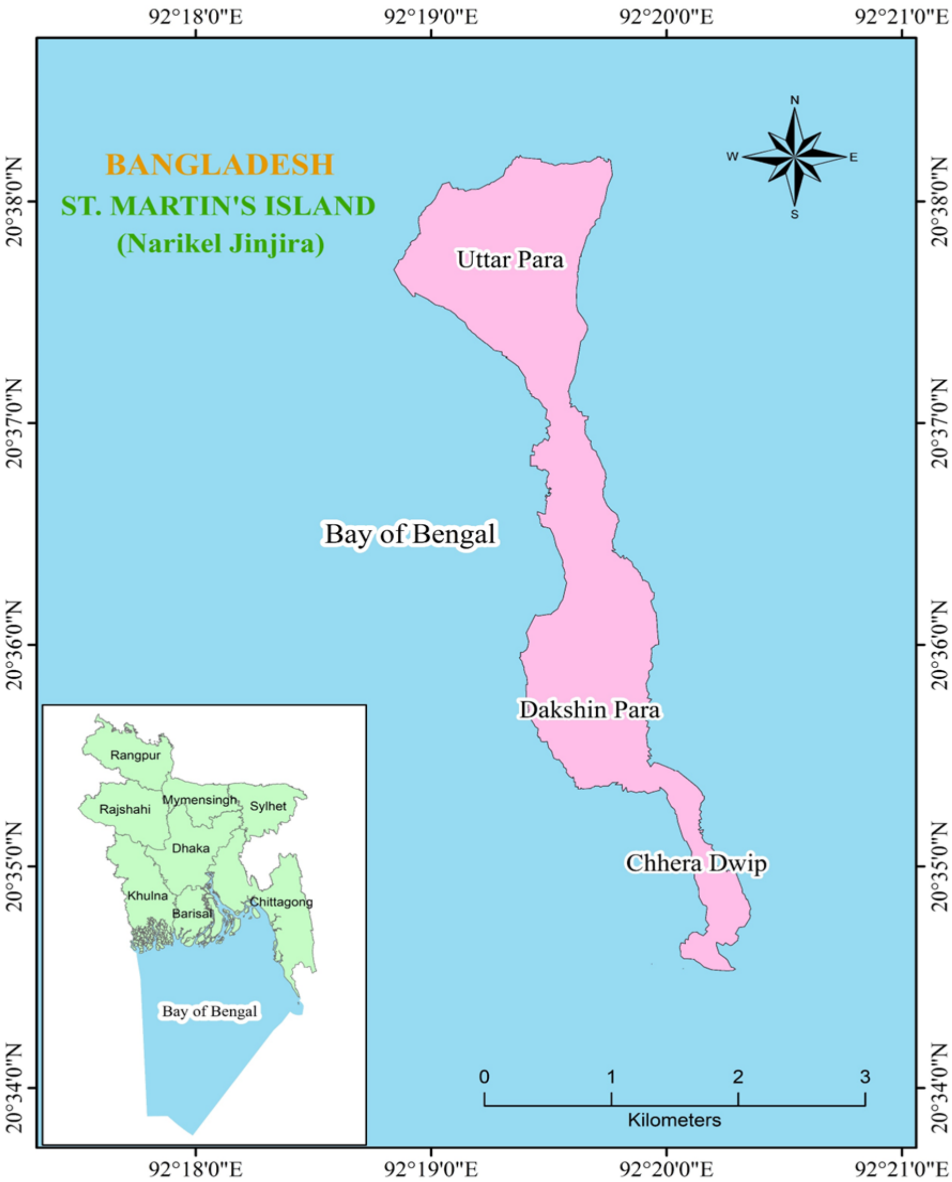


Figure 5.3 St. Martin's Island, Cox's Bazar, Bangladesh (Map of the study area)

Table 5.1 24 Sampling points around the St. Martin's Island with GPS value

Serial	Longitude	Latitude
1	92° 19' 55.47" E	20° 37' 40.94" N
2	92° 20' 4.81" E	20° 37' 18.08" N
3	92° 20' 31.65" E	20° 37' 7.35" N
4	92° 20' 40.79" E	20° 36' 37.39" N
5	92° 20' 22.61" E	20° 35' 58.66" N
6	92° 20' 45.07" E	20° 35' 33.57" N
7	92° 20' 54.33" E	20° 35' 6.52" N
8	92° 21' 12.48" E	20° 34' 21.19" N
9	92° 20' 48.5" E	20° 34' 5.34" N
10	92° 20' 2.12" E	20° 34' 2.95" N
11	92° 19' 30.12" E	20° 34' 24.19" N
12	92° 18' 48.82" E	20° 34' 32.86" N
13	92° 19' 9.99" E	20° 35' 5.3" N
14	92° 18' 34.44" E	20° 35' 14.73" N
15	92° 18' 43.64" E	20° 35' 54.36" N
16	92° 18' 54.57" E	20° 36' 33.53" N
17	92° 18' 28.14" E	20° 37' 3.26" N
18	92° 18' 0.6" E	20° 37' 33.07" N
19	92° 18' 19.3" E	20° 37' 59.57" N
20	92° 18' 29.3" E	20° 38' 34.31"
21	92° 19' 6.13" E	20° 38' 35.31" N
22	92° 19' 38.57" E	20° 38' 59.76" N
23	92° 20' 8.53" E	20° 38' 26.25" N
24	92° 20' 13.81" E	20° 38' 0.05" N

Among the parameters, temperature, pH, DO, salinity, TDS, conductivity, nitrate and phosphate concentration were measured digitally using, mercury centigrade thermometer, portable pH meter, refractometer, TDS meter, EC meter and colorimeter respectively. These measurements helped us narrow down our study to 12 stations for analysis abundance and distribution of physicochemical properties, nutrient, heavy metal and planktons in different seasons of the year. However, for a more accurate reading of physicochemical properties of water samples collected from selected 12 stations was further studied in the laboratory.

5.1.2 Selection of Sampling Stations

Depending on the data (gathered from the digital meters) of temperature, pH, dissolved oxygen (DO), salinity, TDS, conductivity, nitrate, and phosphate the sampling stations were narrow down to 12 stations in the sea surrounding St. Martin's Island. The stations were visited in cool dry winter season, 2019, pre-monsoon, monsoon and cool dry winter season, 2020 and pre monsoon 2021 to collect sample to analysis physicochemical properties of the water and in cool dry winter season, 2019 and pre-monsoon season, 2020 to collect sample to analyze planktons and in cool dry winter season of 2020 and pre monsoon of 2021 to collect sample to analyze nutrient and heavy metal. A total of 12 samples were collected every season of that three years from the selected stations during day time (Table 5.2).

Table 5.2 Selected 12 sampling stations around St. Martin's Island and their GPS values.

Station No	Sample No	Longitude	Latitude
S1	1	92° 19' 55.47" E	20° 37' 40.94" N
S2	2	92° 20' 31.65" E	20° 37' 7.35" N
S3	3	92° 20' 22.61" E	20° 35' 58.66" N
S4	4	92° 20' 54.33" E	20° 35' 6.52" N
S5	5	92° 20' 2.12" E	20° 34' 2.95" N
S6	6	92° 18' 48.82" E	20° 34' 32.86" N
S7	7	92° 18' 43.64" E	20° 35' 54.36" N
S8	8	92° 18' 28.14" E	20° 37' 3.26" N
S9	9	92° 18' 19.3" E	20° 37' 59.57" N
S10	10	92° 19' 6.13" E	20° 38' 35.31" N
S11	11	92° 19' 38.57" E	20° 38' 59.76" N
S12	12	92° 20' 8.53" E	20° 38' 26.25" N

Exposition of the finally selected twelve stations in the map adjacent to the St. Martin's Island was given below (Figure 5.4). The stations could be categorized under three distinct physiographic areas on the Island Uttar Para (S1, S9-12,), Dakhin Para (S2, S3, S7, S8,) and Cheradia (S4, S5, S6) (Thompson & Islam, 2010).

5.2 Seasonal and Spatial Variation of Physicochemical Properties in the Coastal waters adjacent to St. Martin's Island

5.2.1 Physicochemical Properties

The marine environment is a complex system that is largely touched by a wide range of physical, chemical, and biological events. Water's quality, which is a crucial production-limiting factor, can be described in terms of its physical, chemical, and biological characteristics. The biotic communities are impacted by changes in water quality, and the most sensitive species might serve as an indication. Water quality has an impact on a variety of fish behaviors, including reproduction, digestion, excretion, and breeding. Moreover, water quality has a significant impact on fish output. Though not just fish are impacted by water quality; every living thing has a set of optimum water quality conditions that allow them to thrive. If any of these characteristics of the water change, it will have a negative effect on the organism's physiological processes. Monitoring the water's physicochemical properties is crucial for evaluating the ecosystem and water environment as well as for improving the water's quality. Due to the fact that the cultivation of fish and seaweed requires a sufficient, consistent, and ongoing supply of high-quality water, monitoring water quality is also crucial for mariculture.

5.2.2 Objective

Knowledge of physicochemical properties is quite limited, especially in the coastal waters of St. Martin's Island. Planning for mariculture, particularly cage culture and seaweed culture, can be benefited from data on physicochemical properties. To fully comprehend fish production from cage culture and seaweed production from seaweed culture in the coastal water adjacent to St. martin's island is the initial goal. The following are the primary aims of the current study:

1. To determine the spatial distribution of physicochemical properties of coastal waters for selection of suitable site for cage and seaweed culture.

2. To determine the seasonal variation of physicochemical properties of coastal waters for selection of suitable season for cage and seaweed culture.

5.2.3 Materials and Methods

5.2.3.a Water Sample Collection for Analyzing Physicochemical Properties

St. Martin's Island was visited in the year 2019, 2020 and 2021 for collection of samples measuring the physicochemical properties of the water. The parameters of water samples were measured in the cool dry winter season of 2019, three distinct seasons of 2020: the pre-monsoon hot season, the rainy monsoon season, and the cool dry winter season and the pre-monsoon hot season 2021.

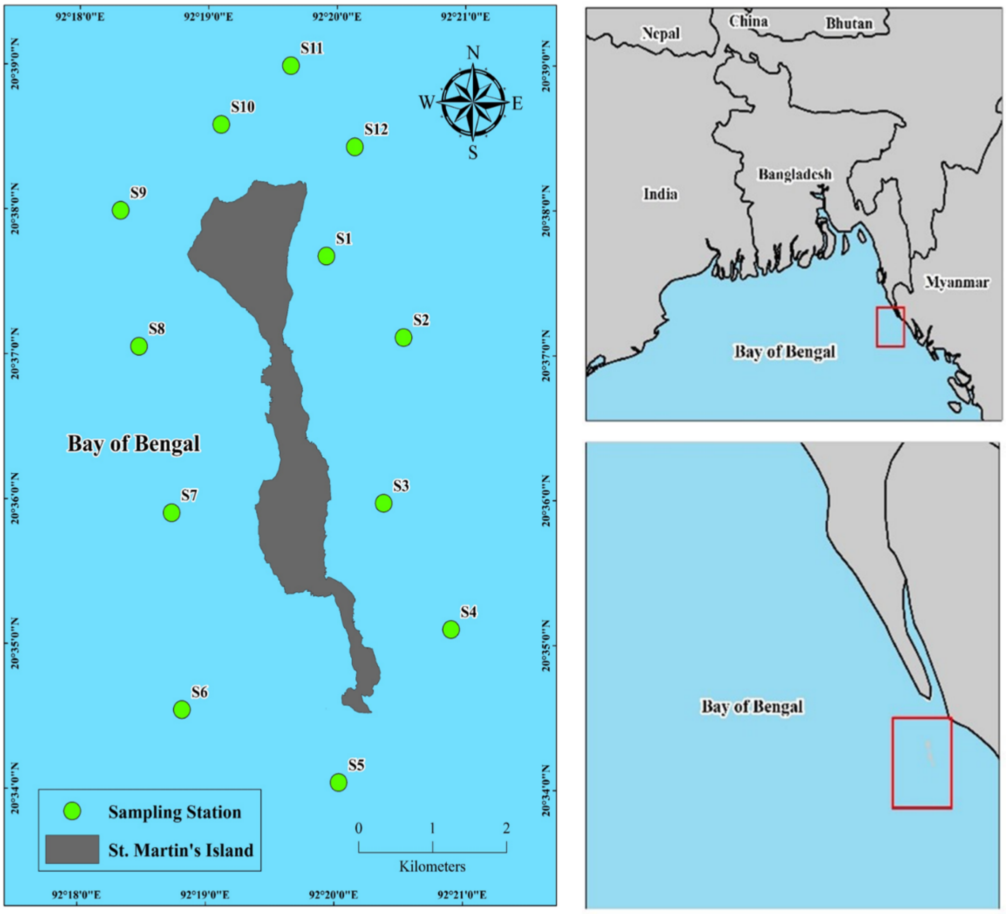


Figure 5.4 Sampling stations for quantitative assessment of physicochemical properties of the coastal waters adjacent to St. Martin's Island.

Seven essential parameters were chosen for physicochemical water quality analysis: temperature, DO, pH, salinity, total dissolved solids, electrical conductivity, and transparency. The temperature of the coastal waters was measured using a mercury centigrade thermometer. The pH and dissolved oxygen (DO) levels were measured using a portable digital pH meter (HANNA, pHep, Romania) and a DO meter (HACH, HQ30d, USA). With the use of a Secchi disc and a refractometer (Agriculture Solutions, WL0020-ATC), the salinity and transparency of the coastal water were measured. The Electric conductivity and TDS were measured using a multiparameter waterproof meter (HANNA, HI98194, Romania).

5.2.3.b Analysis of Physical Properties of Coastal Waters

Water samples were collected from a total of 12 stations strategically positioned around Saint Martin's Island. The specimens were collected using aseptic plastic containers and promptly placed in a refrigerated container following collection and later ransported to the laboratory for the purpose of performing the physical and chemical parameter calculations.

Figure 5.5 Sampling with Niskin water sampler.

The physio-chemical parameters of surface water include dissolved oxygen, temperature, salinity, pH, conductivity, total dissolved solids (TDS), and resistivity. Seawater samples are obtained using a Niskin water sampler and afterwards subjected to immediate field analysis at each sampling location using a YSI water quality multi-probe. The measurement probe was completely submerged beneath the surface of the coastal water, and samples of seawater were collected. Polyvinyl chloride (PVC) water sample vials are utilized for the purpose of collecting 500 cubic centimeters (cc) of water from every designated test station. Prior to the sampling process, the bottles underwent a thorough cleansing procedure involving the application of a detergent solution, followed by three to four rinses with the water being tested, and subsequent drying. The sample vials employ hydrochloric acid as a preservative, and the included samples are promptly sealed to prevent air ingress and stored in a secure location. Each sampling site obtains two duplicates for each parameter. The sample jars are appropriately labeled with identification numbers and securely sealed.

5.2.3.c Measurement of Dissolve Oxygen (DO)

In this study DO values were measured with a DO meter. DO meters typically use a sensor that employs either a Clark electrode or a galvanic cell to measure dissolved oxygen. The Clark electrode is the most common type and operates based on the oxygen reduction reaction at a cathode submerged in the sample solution. In the measurement process Oxygen diffuses through the gas-permeable membrane and reacts at the cathode, causing a reduction reaction. The cathode and anode generate a current proportional to the concentration of oxygen molecules that come into contact with the cathode. The generated current is measured and converted into dissolved oxygen concentration. The meters commonly possess a digital interface that presents the dissolved oxygen content in quantities like as milligrams per liter (mg/L) or parts per million (ppm). Some meters might also provide temperature-compensated readings, as temperature can affect dissolved oxygen solubility.

Figure 5.6 Measuring physicochemical properties of the coastal waters of Bay of Bengal adjacent to St. Martin's Island

5.2.3.d Measurement of pH

The pH values were determined using a pH meter in this investigation. The device consists of three main components: a reference electrode, a pH measuring electrode, and a high input impedance meter. The pH electrode can be likened to a battery that exhibits variable voltage in response to changes in the pH of the tested fluid. The pH measuring electrode is comprised of a glass bulb that exhibits sensitivity to hydrogen ions. Consequently, any fluctuations in the relative concentration of hydrogen ions between the external and internal environments of the bulb result in corresponding variations in its millivolt output. The influence of the hydrogen ion's behavior on the output of the reference electrode has been eliminated. The pH electrode's internal resistance, which is significantly elevated, poses challenges in accurately measuring the voltage change induced by pH variations. The variables of leakage resistances and the entry impedance of the pH meter are of utmost importance. The pH meter functions as a high impedance amplifier, accurately detecting and displaying minute electrode voltages in pH devices using both analog and virtual displays. The study of voltages may be necessary for some programs or when utilizing ion-selective or Oxidation-Reduction Potential (ORP) electrodes.

5.2.3.e Measurement of Salinity

The measurement of salinity, defined as the collective quantity of dissolved inorganic substances, involves the process of water evaporation followed by the measurement of the resulting residue. The method at hand presents a considerable challenge due to the need for changes to account for the escape of carbon dioxide and hydrogen chloride throughout the evaporation process. Furthermore, the aforementioned strategies pertaining to weight management are ineffectual in maritime environments. Hence, it is imperative to employ indirect strategies when managing a delivery system. In the field of oceanography throughout the previous century, the measurement of salinity in seawater samples was mostly conducted using two main methods: chlorinity titration and conductometry. The refractometer was utilized in this investigation for the purpose of quantifying salinity levels.

5.2.3.f Measurement of Electrical Conductivity (EC)

An electric conductivity meter, also referred to as an EC meter, is widely regarded as the most effective device for assessing the salinity levels in soil. While the cost of a high-quality EC meter may exceed that of a refractometer or hydrometer, it possesses the capability to measure both the salinity and conductivity of water. The measurement of water conductivity was conducted using an EC Meter in this study.

5.2.3.g Measurement of Temperature

During the course of the experiment, the probe was completely immersed in the water, collecting samples of seawater at a minimum depth of 30 cm beneath the surface. Temperature readings were obtained from 12 distinct sample locations during the course of the excursion, utilizing a multimeter probe. The temperature was expressed in degrees Celsius (°C). The temperature in this investigation was measured using a Mercury centigrade thermometer.

5.2.3.h Measurement of Total Dissolve Solid (TDS)

Total dissolved solids are a measurement of the total amount of all dissolved inorganic and organic components, whether they are in the form of molecular, ionized, or microgranular suspended particles, in a liquid. Parts per million are a common unit of reporting for TDS concentrations. Digital meters can be used to measure the TDS levels. In this study TDS meter was used to measure the total dissolve solid of the coastal water adjacent to St. Martin’s Island.

5.2.4 Analysis of Data

All the parameters were measured immediately after collecting the water sample using respective instruments. For rechecking some of the parameters water sample was also transferred to laboratory and further investigated to ensure the accuracy of the value. The required computer-based analyses were conducted using MS Excel 2019. For graphical and data visualization Graph Pad Prism and ArcGIS were used respectively.

5.3 Abundance and Distribution of Phytoplankton in the Coastal waters adjacent to St. Martin’s Island

5.3.1 Phytoplankton

The plants that dwell in the ocean's upper sunlit layer and adopt this way of life are known as phytoplankton. Phytoplankton, which are primarily unicellular and possess the ability to create chemical energy from light, are little plants that exist in a free-floating state inside the euphotic zone, the uppermost layer of water that receives ample sunlight. Despite making up less than 2% of the total ocean water, this region is crucial to the survival of most pelagic marine life.

In aquatic habitats, all of these plants, which account for a sizeable portion of primary output, play a significant role in primary production, nutrient cycling, and food webs. The other five main prevalent forms of phytoplankton found in the oceanic environment are diatoms, dinoflagellates, coccolithophorids, silicoflagellates, and photosynthetic bacteria.

5.3.2 Objectives

From marine ecosystem particularly in the Bay of Bengal, knowledge on phytoplankton is really sparse, especially in the coastal waters of St. Martin's Island. Planning for mariculture, particularly cage culture, and the maintenance of ocean biogeochemical cycles can benefit from data on phytoplankton. As a result, the first aim is to gain a thorough understanding of fish production and plankton productivity in the BoB. The main goals of the present research are as follows:

1. To determine the abundance and diversity of phytoplankton to know about the primary productivity of coastal waters of the St. Martin’s Island.
2. To determine the distribution of phytoplankton to identify the suitable site for cage culture of phytoplankton feeder fish in the coastal waters adjacent to St. Martin’s Island.

5.3.3 Material and Methods:

5.3.3.a Sample Collection and Preservation

For the purpose of this inquiry, samples were collected from 12 sampling stations (Figure 5.7). The sampling sites were visited during the cool dry winter season 2019 and pre-monsoon hot season 2020, and one sample was taken from each location. As a result, there were 12 samples from 12 stations covering the time span at the end during each season.

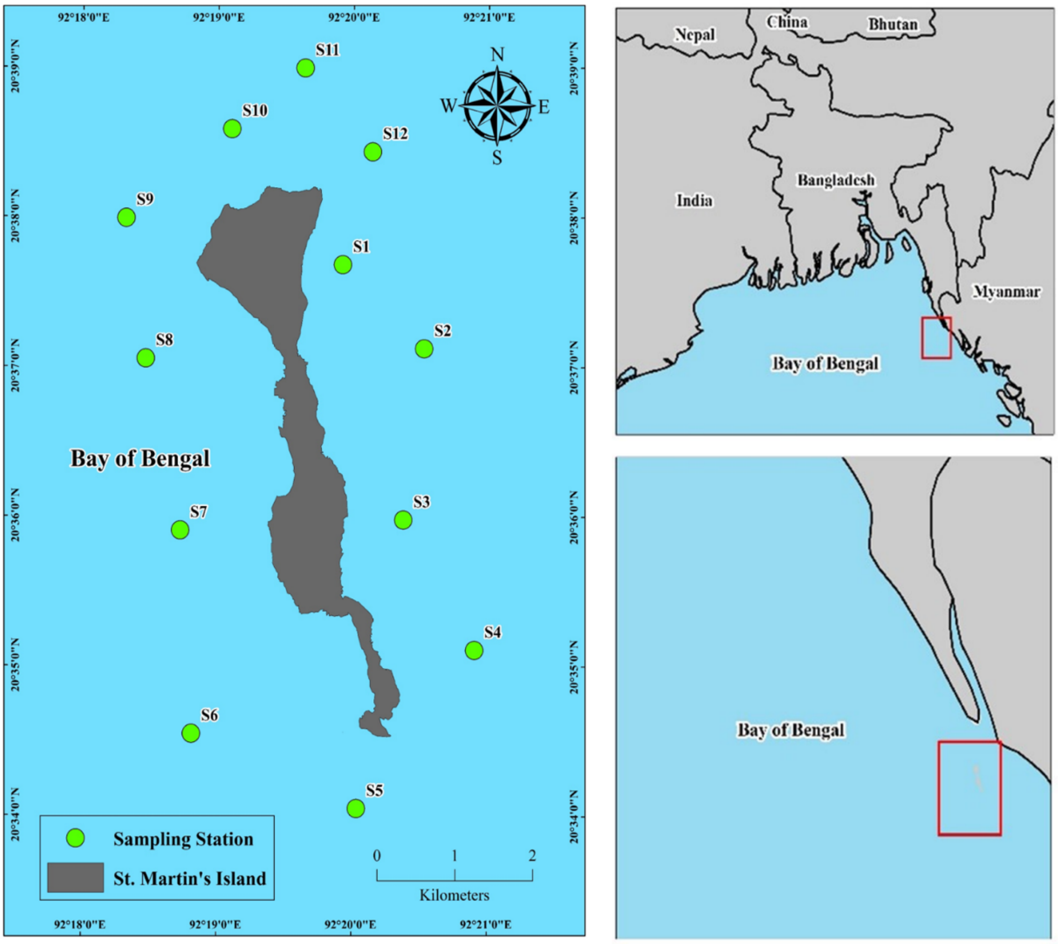


Figure 5.7 Sampling stations for quantitative and qualitative assessment of phytoplankton in the coastal waters adjacent to St. Martin's Island.

After running 20 L of seawater through a 20 μm mesh phytoplankton net at each site, samples of phytoplankton were taken. After being decanted into a 250 mL plastic vial, the concentrate was stored by being mixed with Lugol's solution.

Figure 5.8 Collection of water sample for quantitative and qualitative assessment of phytoplankton in the coastal waters adjacent to St. Martin's Island.

The specimens were prepared for transportation, securely sealed, and appropriately labeled with the corresponding date and time. Simultaneous in situ measurements of physicochemical water quality parameters were conducted alongside the collection of phytoplankton samples.

Figure 5.9 Use of compound microscope to identify the genus and species of phytoplankton

The surface water's temperature was determined using a mercury centigrade thermometer. A portable digital pH meter was used to measure the pH of the water (HANNA, pHep, Romania). A portable digital DO meter and a refractometer were used, respectively, to measure the salinity and DO (Agriculture Solutions, WL0020-ATC; HACH, HQ30d, USA). All of the samples were collected, given ice packs, and transferred within 24 hours to the lab at the Department of Oceanography, University of Dhaka. The analysis got under way right afterwards and was finished in the following 72 hours.

5.3.3.b Analyses of Biological Parameters

On a glass slide, a coverslip was placed over a drop of plankton concentration. The genus and species of the preparation were subsequently determined using a compound microscope (Novel, N10E, China). Tomascik (1997), Hasle & R (1997), Davis (1955) were used to identify the organisms. Using a Sedgewick Rafter Counting Chamber (S-R) and a student microscope with a 400x magnification, the phytoplankton density was calculated. The S-R cell was housed in a 50x20x1 mm rectangular chamber with a 1000 mm^2 surface area and 1000 mm^3 volume. 1 ml of concentrated sample was collected and placed on the grids of the cell. The prevention of air bubble formation within the cell was achieved by placing the cover slip diagonally over it. The SRCC was not overfilled in order to guarantee a reliable count. Based on taxa, the phytoplankton population density from each mount of the S-R was measured. The following formula was used to get the final phytoplankton density.

$$\text{Number of organisms } (m^{-3}) = (C \times V_1) / (V_2 \times V_3)$$

Here,

C= number of organisms counted,

V_1 = Volume of concentrated sample (ml),

V_2 = Volume of sample counted (ml),

V_3= Volume of filtered water by the plankton net (m^3).

Species richness (Df) was used to calculate the number of genera in the sample using the counting data. The sample's species richness was calculated using Margalef's approach from 1958.

$$\textbf{Species richness, } D_f = (S-1)/\ln(N)$$

Here,

S = number of genera in a sample

N = total number of genera

In order to assess the generic variety at a sampling station, the Shannon-Wiener index (H) was used. The Shannon-Wiener index is calculated using the following equation:

$$\textbf{Shannon-Wiener index, } H = -\sum P_i \times \ln(P_i) \textbf{ and } P_i = n/N$$

Here,

n = total number of individuals in a sample

N = total number of individuals

All of the calculations for the diversity were done while taking into account the population density at the genus level.

5.3.3.c Analysis of Data

The phytoplankton data were digitized using an excel spreadsheet (Microsoft Excel version 19), and afterwards organized into tables and figures using standardized units of measurement. Graph Pad Prism and ArcGIS were utilized for the graphical and data visualization, respectively.

5.4 Abundance and Distribution of Zooplankton in the Coastal waters adjacent to St. Martin’s Island

5.4.1 Zooplankton

Zooplankton are animal plankters that reside in the ocean's upper layer and have the ability to move. However, they are either immobile or are limited to vertical movement, which prevents them from determining their horizontal positions. In all oceans, it is believed that zooplankton occupy the first trophic position in the food chain that transfers nutrients from phytoplankton to grazing animals. In addition to their taxonomy, zooplankton are categorized according to their size. Larger plankton animals are often caught by streaming nets out from a fixed item in swift water or pulling finely woven conical plankton nets behind a vehicle. The plankton size class determines the size of the openings in the netting material. The smaller varieties of plankton are typically collected using capturing water bottles since nets that are small enough to capture them clog fast when pulled.

5.4.2 Objectives

The current understanding of zooplankton, primarily in the Bay of Bengal, notably in the coastal waters of St. Martin's Island, is characterized by a significant lack of comprehensive knowledge. The utilization of zooplankton data holds significant potential for applications in mariculture, particularly in the context of cage culture for zooplankton feeder fish, as well as the conservation of ocean biogeochemical cycles. The primary objective is to gain a comprehensive understanding of fish output and plankton productivity in the Bay of Bengal (BoB). The following are the primary aims of the current study:

1. To determine the abundance and diversity of zooplankton of the coastal waters adjacent to the St. Martin's Island.
2. To select the best location for cage culture of zooplankton feeder fish by determining the distribution of zooplankton in the coastal waters of St. Martin's Island.

5.4.3 Materials and Methods

5.4.3.a Sample Collection and Preservation

The investigation was conducted at 12 distinct locations, all of which were near the surrounding the BoB's St. Martin's Island and between 20°34 and 20°39 N and 92°18 and 92°20 E during cool dry winter season and pre-monsoon hot season. The research locations' full descriptions and GPS readings for the stations have already been mentioned.

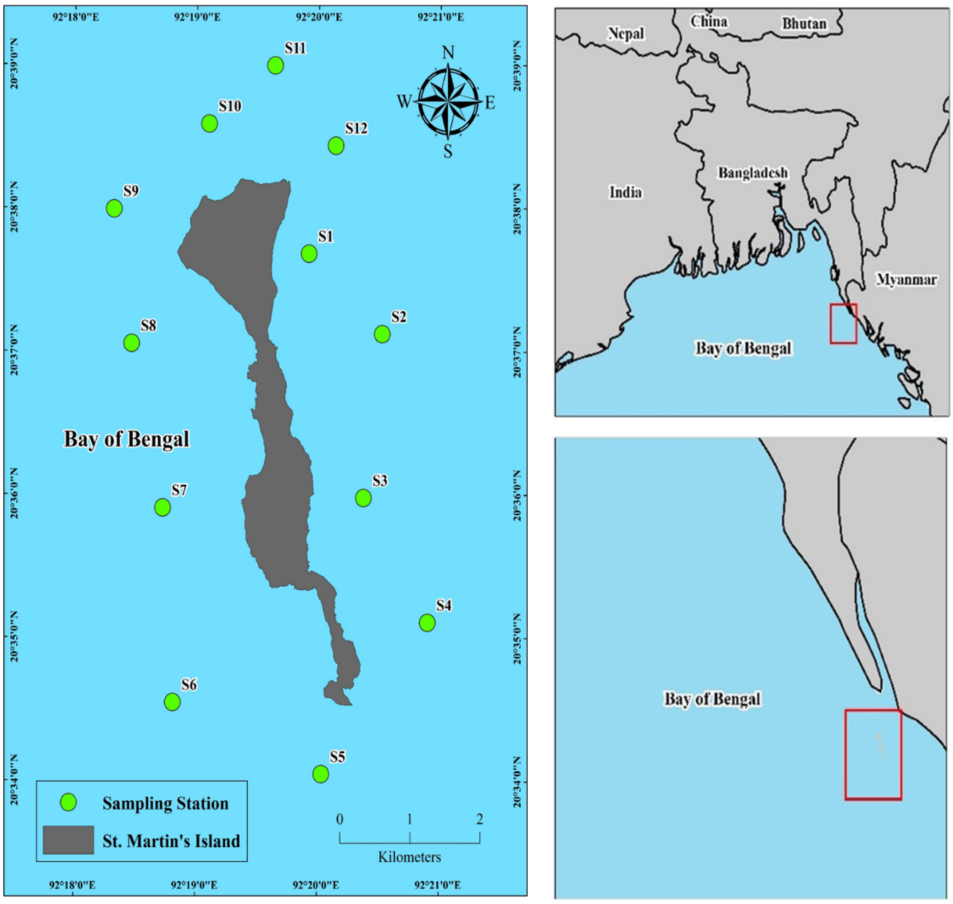


Figure 5.10 Sampling stations for determining zooplankton abundance and diversity in the coastal waters adjacent to St. Martin's Island.

The study stations were visited in 2019 during cool dry winter season and pre-monsoon hot season 2020 to gather zooplankton samples. A motorized trawler was used to help transport crew members to each station. 100 L of saltwater were funnelled through a plankton net with the use of a plastic bucket (10 L in capacity) that had a mesh size of 60 µm and an opening mouth diameter of 0.57 m. The decantation process involved transferring the concentrated plankton from the plankton net bucket into a screw-capped polystyrene bottle with a volume of 500 ml. A 5% formaldehyde solution was used to preserve the specimen while labelling it.

5.4.3.b Analyses of Biological Parameters

The entirety of the collected samples was promptly conveyed to the Biological Oceanography Laboratory, which is affiliated with the Department of Oceanography at the esteemed University of Dhaka, inside a span of 24 hours. The physicochemical parameters were determined from both field and laboratory measurements conducted at the study stations.

Figure 5.11 Collection of water sample for quantitative and qualitative assessment of zooplankton in the coastal waters adjacent to St. Martin's Island.

First, the species of each zooplankton sample concentrate taken from the 12 locations was determined. A compound microscope (Novel, N10E, China) with a camera attachment was employed for the project. A glass slide with a cover slip was created with a water mount sample added to it with 4% glycerin, and it was examined under a microscope. Photographs of the species and microscopic measurements of the individuals were taken with the help of the software Zooscan. Several researchers have made significant contributions to the identification of the species, including Slotwinski et al. (2014), Abou Zaid et al. (2014), Conway et al., (2003), Kasturirangan (1963) and Davis (1955).

The quantification of the zooplankton population in the obtained samples was conducted using a Sedgewick Rafter Counting Cell (SRCC) and a compound microscope set at a magnification of 100×. The population density of zooplankton was estimated based on taxa at each mount of the Swire Research Center for Coastal Studies (SRCC).

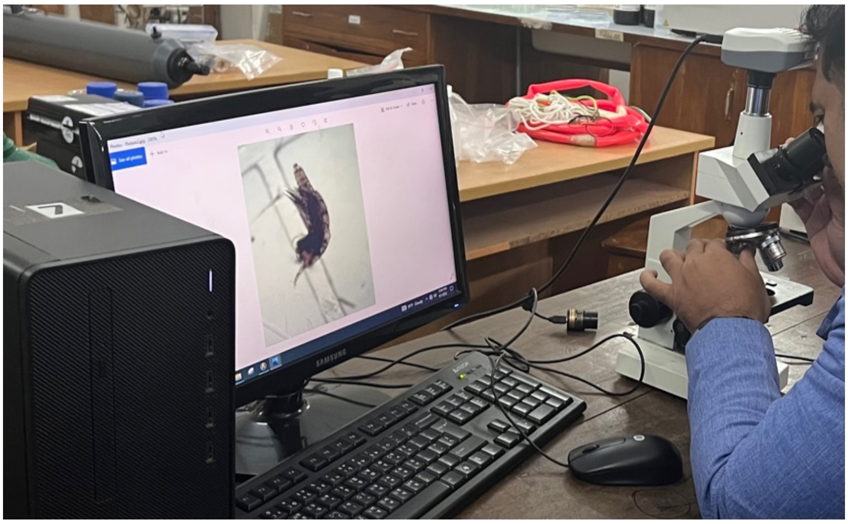


Figure 5.12 Use of compound microscope to identify the genus and species of zooplankton

The formula employed in quantifying the organisms contained in each sample was as follows:

Number of organisms (m^{-3}) = $(C \times V_1) / (V_2 \times V_3)$

Here,

C = number of organisms counted,

V_1 = volume of concentrated sample (ml),

V_2 = volume of sample counted (ml),

V_3 = volume of filtered water by the plankton net (m^3)

The assessment of species richness and generic diversity in the samples was conducted using the Margalef (1958) paradigm, employing the measures of species richness (D_f) and the Shannon-Wiener index. The following methods were employed to calculate the Shannon-Wiener index and species richness:

Species richness, $D_f = (S-1)/\ln(N)$

Here,

S = number of genera in a sample

N = total number of genera

Shannon-Wiener index, $H = -\sum P_i \times \ln (P_i)$ and $P_i = n/N$

Where,

n = total number of individuals in a sample

N = total number of individuals

The population density at the genus level was taken into consideration for all diversity calculations.

5.4.3.c Analysis of Data

After the zooplankton data were converted to digital form with the use of an Excel spreadsheet (version 19 of Microsoft Excel), tables and figures were constructed with the aid of international units of measurement. The data was properly checked before being plotted and tallied. For graphical and data visualization Graph Pad Prism and ArcGIS were used respectively.

5.5 Spatial Distribution and Seasonal Variation of Nutrients in the Coastal waters adjacent to St. Martin's Island

5.5.1 Nutrient

Due to their participation in several functional biochemical processes, nutrients in ocean water are essential for biological productivity, management of aquatic ecosystems, and the existence of living things. From phytoplankton to zooplankton, which are the principal food providers, nutrients play a part. In order to produce amino acids, proteins, and related compounds that are eventually devoured by creatures higher up the food chain, phytoplankton mostly use nutrients. The ecological components are concerned when there is an excessive concentration of nutrients in the ocean water because it reduces biological productivity and affects biogeochemical processes, which causes eutrophication or nutrient enrichment of the coastal waters. It is evident to follow the source of nutrients and to take the necessary precautions in order to verify the nutrient enrichment in ocean water. For both natural and manmade reasons, the concentration of nutrients may increase. Land and sea collide in coastal or island areas, which naturally results in nutrient enrichment. In addition, several sources are contributing to the growth in nutrient concentration in ocean water and sediment, even when anthropogenic causes are taken into account. Consequently, it is essential to evaluate nutrient distribution, variations in nutrient concentration, composition, and source identification in order to use them as a theoretical and numerical framework for creating the necessary strategies for the preservation of ecological balance and ecosystem resilience.

5.5.2 Objectives

The most important aspect of sea water that affects marine life is its concentration of soluble nutrients. The two nutrients that are most crucial for promoting primary production by plankton in the oceans are nitrogen and phosphorus. The primary productivity of the area is mostly dependent on the nutrient concentration of the water bodies that surround St. Martin's Island. The following goals guided the current study:

1. To investigate the spatial distribution of nutrients of coastal waters for selection of suitable site for cage and seaweed culture.
2. To determine the seasonal variation of nutrients of coastal waters for selection of suitable season for cage and seaweed culture.

5.5.3 Materials and Methods

5.5.3.a Fieldwork

For the purpose of choosing a site for cage culture and seaweed cultivation, two field works were carried out in 2020 during the chilly dry winter season and 2021 during the pre-monsoon dry season. During the field study, factors such as the sources of pollution, the ways in which the local population makes a living, the surface geology of the region, and patterns of land use, as well as the soil type and drainage pattern of the region, were observed.

5.5.3.b Site Selection for Seawater Sampling

Seawater nutrient concentration can best be evaluated by chemical analysis of seawater samples collected from suitably located area. Twelve sites were selected (Fig. 5.13) adjacent to the Saint martin's island depending on initial data gathered from 30 different sampling point as mentioned above. The following factors was considered when selecting sampling location include:

a) Purpose of the sampling,
b) Seawater characteristics,
c) Purpose of monitoring seawater, and
d) Anthropogenic influences.

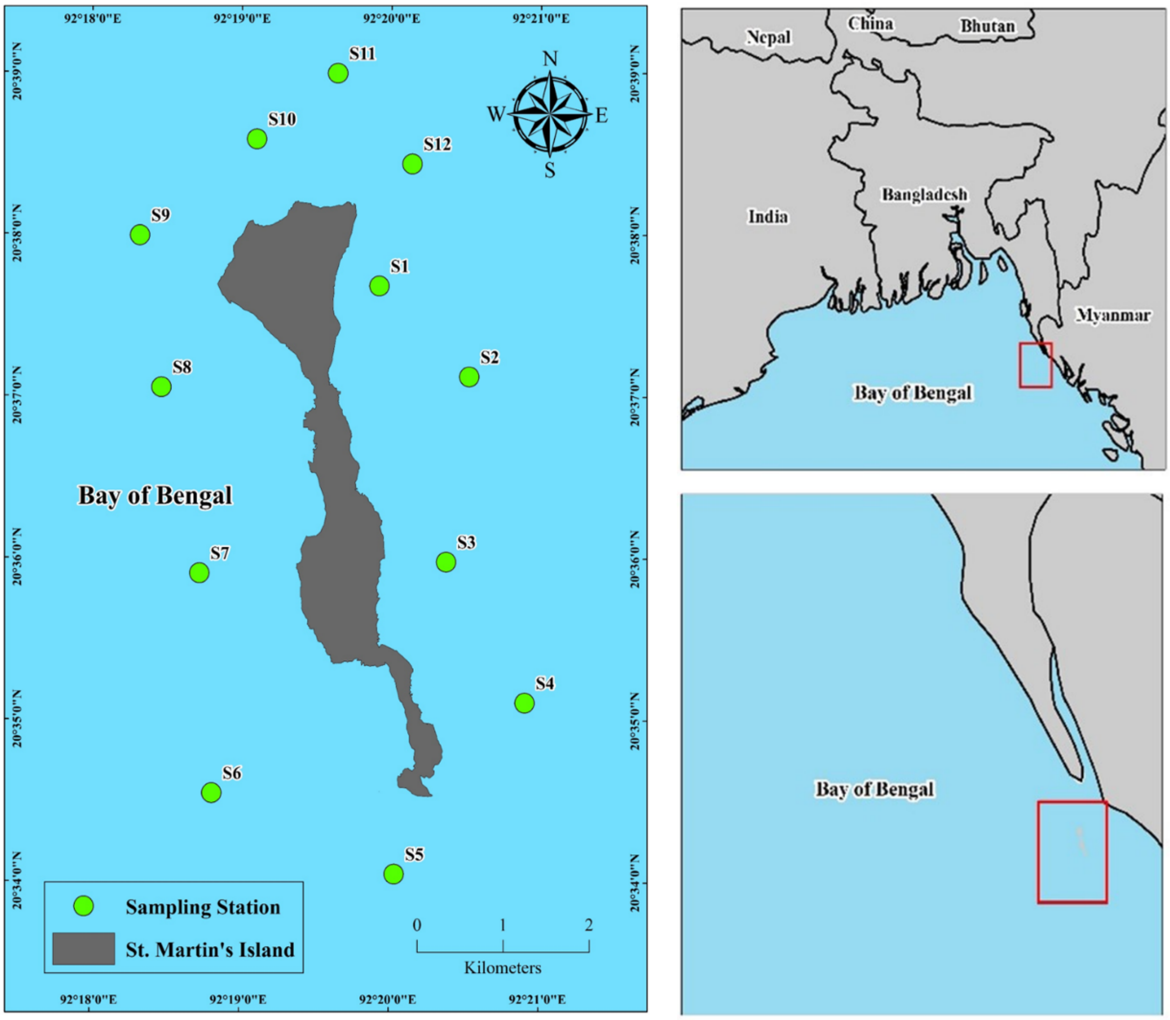


Fig 5.13 Sampling stations for determining nutrient's seasonal variation and distribution in the coastal waters adjacent to St. Martin's Island.

5.5.3.c Surface Water Sampling

Proper sampling is very important for seawater nutrient study. As the number of locations was large, it was not possible to sample all of the area. So, a limited number of locations were selected which can give indicative results. For this purpose, a total of 12 seawater samples collected from the adjacent area of the island during October, 2020 and March, 2021. During sample collection, the research seeks to complement the peripheral of St. Martin's Island. The 12 seawater samples were collected at depths ranging from 0 to 3 meters using a Niskin water sampler.

5.5.3.d Sample Processing and Chemical Analysis

The seawater samples were preserved in PVC bottles that were initially rinsed with deionized water (resistivity >18 MΩ.cm). The procedure was duplicated, per APHA 2012, to assure adherence to the quality assurance and quality control standard methodology. A 0.45 m syringe-head membrane filter was used to filter the samples after they were collected. The samples were then sealed and kept at a temperature of no more than 4° C before being transported to the lab for additional examination. Initial measurements and documentation were done on-site using calibrated portable instruments for temperature (T), pH, electrical conductivity (EC), and total dissolved solids (TDS). To assign the geographical position of the sampling site a handled GPS meter was used. In the laboratory analysis, the concentrations of nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4+), phosphate (DIP), and dissolved silicate (DSi) were measured through flow injection analysis (QuAAtro, Bran+Luebbe, Germany). The study adhered to safety, chemical, and standard operating procedure (SOP) protocols in the lab.

Seawater contains dissolved inorganic nitrogen (DIN), which comprises nitrate and nitrite ions. Additionally, dissolved inorganic phosphate (DIP) in seawater consists of phosphate ions, while dissolved inorganic silicate (DSi) is composed of silicate ions. The concentrations of nitrate (NO_3^-),), nitrite (NO_2^-), ammonium (NH_4^+), phosphate (PO_4^-), and dissolved silicate (SiO_4) were measured in the laboratory analysis. The standard spectrophotometric procedures outlined by(Grasshoff et al., 1999) were followed using a double-beam spectrophotometer (Shimadzu UV–Visible 1800). The research adhered to established standard operating procedures (SOPs) for laboratory operations, chemical handling, and safety protocols. Furthermore, the blanks were prepared and the glassware was washed and rinsed with meticulous care.

Figure 5.14 Sampling of coastal waters adjacent to St. Martin's Island for nutrient analysis

5.5.4 Analysis of Data

Some of the parameters were measured immediately after collecting the water sample using respective instruments and later all of the samples were transferred to laboratory for investigation. They were investigated and properly measured in the laboratory. As the data were converted to a digital format, tables and figures were constructed with the aid of metric and other international units of measurement. The required computer-based analyses were conducted using MS Excel 2019. Before being plotted and tallied, the data was thoroughly inspected. Graph Pad Prism and ArcGIS were utilized for graphical and data visualization, respectively. In this study, a combined array of methods, particularly Principal Component Analysis (PCA), and Hierarchical Cluster Analysis (HCA), were taken into account for understanding the relationships among the parameters considered for Saint Martin's Island using statistical software, namely SPSS (version 20). PCA was executed in this study to determine the sources of the nutrients and oceanic processes relevant to the variant concentration accumulation and distribution in the studied marine ecosystem. Hierarchical cluster analysis (HCA) was used to categorize the nutrient concentration and its accompanying Physico-chemical parameters into a cluster based on the variables specified (Hasan et al., 2022). A part from this, The Pearson's correlation method was used to identify the similarities and differences between variables by evaluating linear relationships Hasan et al. (2021). The Pearson's correlation ranges from -1 to +1.

5.6 Seasonal and Spatial Distribution of Heavy Metals in the Coastal waters adjacent to St. Martin's Island

5.6.1 Heavy Metal

Estuaries and coastal areas absorb substantial anthropogenic inputs originating from both point and non-point sources upstream, as well as from metropolitan areas, enterprises, and industries located along the borders of the estuary. It is now well acknowledged that heavy metal pollution in estuaries and coastal areas is a severe environmental problem. Some heavy metals, including copper, cobalt, zinc, iron, and manganese, are necessary for numerous biological processes and enzymatic activity at low concentrations. Other metals, such as cadmium, mercury, and lead, are hazardous even at low quantities and are not known to play any vital roles in living things. Studies on heavy metals are generally essential from the perspectives of the aquatic environment and the public health. The aquatic environment contains heavy metals, which can build up along the food chain. Moreover, small quantities of heavy metals that are consumed are either transformed into metabolically inert forms and stored in the body temporarily or permanently, or they are stored in a manner that allows them to be metabolically utilized for essential biochemical processes. Salinity, pH, and water hardness are a few examples of environmental factors that can play a significant role in the accumulation of heavy metals in living things to dangerous levels and harm the environment.

Therefore, the purpose of this study is to look at the amounts of heavy metals in the coastal water around St. Martin's Island. Heavy metals, notably Pb, Cu, As, Cr, Cd, and Zn, were considered in order to comprehend the island's geo-chemical context as well as their ecological and human health risks in this study. Mercury (Hg) was also examined, however after laboratory testing it was determined that the amount of mercury in the collected sample was minimal, hence this criterion was omitted.

5.6.2 Objective

1. To investigate the spatial distribution of heavy metal of coastal waters for selection of suitable site for cage and seaweed culture.
2. To determine the seasonal variation of heavy metal of coastal waters for selection of suitable season for cage and seaweed culture.

5.6.3 Materials and Methods

5.6.3.a Site Selection for Seawater Sampling

The easiest way to determine the concentration of heavy metals in seawater is to chemically analyze samples that were taken from an appropriate location. On the basis of the preliminary information obtained from the 24 distinct sampling points stated above, twelve sites (Fig. 5.15) close to St. Martin's Island were chosen for sampling of heavy metal distribution.

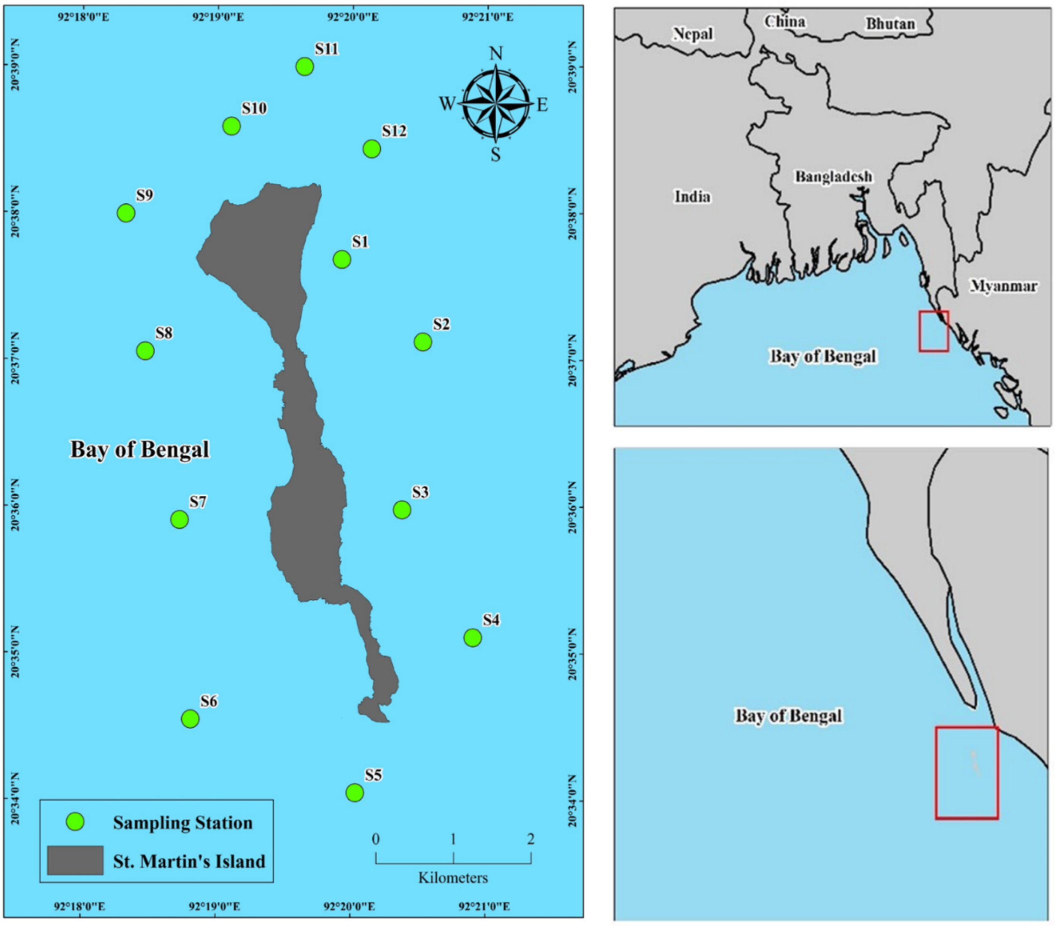


Fig 5.15 Sampling stations for determining heavy metal's seasonal variation and distribution in the coastal waters adjacent to St. Martin's Island.

5.6.3.b Samples Collections

Samples were collected from selected 12 sampling stations around the St. Martin's Island (Figure 5.15). Two field works were carried out in 2020 during the chilly dry winter season and 2021 during the pre-monsoon dry season to collect the sample. The samples were taken with a water sampler from at least 30 cm below the water's surface and kept in a 10-litre high density polyethylene container that had already been cleaned. During the fieldwork, the in-situ parameters of the water quality were measured by using multi-probes that had been previously calibrated.

5.6.3.c Samples Preparations

To halt biological activity and guarantee that all chemicals were present in the water column, the obtained water samples were acidified to a pH of 2 using concentrated nitric acid (HNO_3). Subsequently, the water samples underwent filtering by vacuum filtration utilizing cellulose acetate membrane filters with a pore size of 0.45 µm. This filtration process aimed to extract dissolved metals from the samples while preventing any obstruction of the spectrometer equipment during subsequent analysis. Finally, filtered water samples were diluted ten times with pure water and kept at 4^oC until analysis.

5.6.3.d Sample Processing and Chemical Analysis

All the parameters (Pb, Cu, As, Cr, Cd and Zn) were measured immediately after collecting the water sample using respective instruments. The following analytical technique could be used to determine the concentrations of heavy metals.

Inductively Coupled Plasma Mass Spectrometry (ICP-MS): This technique provides high sensitivity and can detect a wide range of metals simultaneously.

Atomic Absorption Spectrometry (AAS): AAS is often used for specific metal analysis and offers good sensitivity.

Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES): Similar to ICP-MS, but measures the emission lines of elements.

Voltammetry: An electrochemical technique that can provide accurate measurements of trace metals.

This study employed Inductively Coupled Plasma Mass Spectrometry (ICPMS) to analyze the presence of heavy metals in seawater. For seawater, results were given in micrograms per liter (µg/L). These methods are exceptionally sensitive and accurate, which enables the detection of metal ions in extremely minute quantities. A blank analysis using deionized water and an analysis of a standard reference material (SRM) containing known quantities of metal were carried out so that the accuracy and precision of the results could be guaranteed. To ensure the reliability and validity of the outcomes, it is essential to follow standard operating procedures (SOPs) and quality control techniques. In addition to this, it is essential to interpret the findings in light of the regulatory rules and environmental standards that are in place. Heavy metal health and pollution index was measured as heavy metal has a detrimental impact on fish, seaweed and any other living organism of the ocean and ultimately on human health.

5.6.3.e Heavy Metal Health and Pollution Index

Heavy metal pollution index (HPI): The HPI provides numerical value to track the frequency and degree of heavy metal pollution in collected seawater. The index enables to estimate the extent of heavy metal pollution that impacts human health and the marine environment. In this study, China's standard for seawater quality is used as the standard concentration limits.

Heavy metal evaluation index (HEI): The Heavy Metal Evaluation Index (HEI) is a numerical value that reflects the level of heavy metal contamination in a given area (Edet & Offiong, 2002; Piroozfar et al., 2021; Prasanna et al., 2012). The HEI is calculated by measuring the concentration of one or more heavy metals in a sample (e.g., soil, water, air), and then comparing the results to established standards.

Nemerow Pollution Index (NPI): The Nemerow Pollution Index (NPI) is a composite index that measures the overall level of pollution of water, soil or air in a given area. The NPI enables to track the changes in the level of pollution over time. In this study, the index is taken into account to enumerate the sea surface water pollution and water quality in the vicinity of St. Martin's Island.

Total ecological risk index (TERI): The Potential Ecological risk (PER) approach is a method that is used in order to assess the risk that is caused by heavy metal concentration in seawater. PER is equal to the sum of all the elemental risk $E^i{}_r$. Primarily, the risk ($E^i{}_r$) for each individual element is determined by multiplying the toxic response factor and contamination factor. The Potential Ecological Risk (PER) is quantified as the cumulative sum of individual elemental sensitivities (Ei r) within a given biological community, serving as an indicator of its susceptibility to toxic compounds and the overall ecological risk it may face.

5.6.3.f Analysis of Data

The transportation of all samples to the laboratory was conducted in order to facilitate their subsequent analysis. They were examined and measured accurately in the laboratory. As the data were being transformed to a digital format, tables and graphs were created using metric and other international units of measurement. The necessary computer-based analyses were carried out using Microsoft Excel 2019. Before being plotted and tallied, the data were meticulously examined. Graph Pad Prism and ArcGIS were used, respectively, for graphical and data visualization.

The HPI was computed utilizing the formula proposed by Mohan et al. (1996) -

$$HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i},$$

In this context, the variables Qi and Wi represent the sub-index and unit weight of parameter i, respectively. The variable n denotes the total number of parameters being examined.

The sub-index Qi is determined using by the following formula-

$$Q_i = \sum_{i=1}^{n} \frac{|M_i - I_i|}{W_i - I_i} \times 100,$$

The variables Mi, Ii, and Si represent the measured heavy metal concentration, desirable concentration, and standard suggested concentration of parameter i, respectively. The symbol (-) represents the absolute value of the numerical discrepancy between two values, disregarding the algebraic sign.

HEI is calculated as follows:

$$HEI = \sum_{i=1}^{n} \frac{H_c}{H_{max}},$$

The variables Hc and Hmax represent the measured concentration and maximum allowable concentration of parameter i, respectively. The Heavy Metal Evaluation Index, alternatively referred to as the Metal Index (Mi) according to (Tamasi & Cini, 2004), is a recognized term in the field.

NPI also provides categorizing water quality by the way one specific element affects water (Brady et al., 2015) and usually calculated by the equation given below:

$$NPI = \sqrt{\frac{[(1/n)\Sigma(C_i/S_i)]^2 + [\max (C_i/S_i)^2}{2}},$$

The observed concentration and standard concentration of the heavy metal i are Ci and Si, respectively, and the number of indices is represented by n. When evaluating the quality of the water, the secondary seawater quality standard (GB3097-1997) that is used in China was taken into consideration as a reference. The NPI categorizes metal pollution in seawater into six distinct categories. A value of ≤0.5 signifies the absence of pollution, while a range of 0.5–0.7 shows cleanliness. The range of 0.7–1.0 denotes a warm condition, while a range of 1.0–2.0 implies pollution. A value of 2.0–3.0 indicates moderate pollution, and a value over 3.0 signifies severe pollution (Li et al., 2001; Liang et al., 2017)

The calculation of the PER is determined by employing the formulae outlined by Guo et al. (2010):

$E^i_r = T^i_r \times C^i_f$;

$C^i_f = C^i / C^i_n$

$C_d = \sum_{i=1}^{n} \quad C^i_f$

And

$PER = \Sigma\ E^i_r (m, i = 1)$

The variable Ei r denotes the ecological risk index pertaining to an individual element, while Tir indicates the biological toxic factor associated with each respective element. The variables Ci and Cin represent the content of the element in the samples and the reference value of the element, respectively.

The ecological risk associated with a single heavy metal element is classified into five categories based on intensity: low risk (Eir < 40), moderate risk (40 ≤ Eir < 80), considerable risk (80 ≤ Eir < 160), high risk (160 ≤ Eir < 320), and very high risk (Eir ≥ 320) (Guo et al., 2010; Suresh et al., 2012; Hakanson, 1980). The comprehensive evaluation of ecological risk (PER) for each site involves the summation of elemental Eir values, which are subsequently categorized into four distinct levels: low risk (PER < 95), moderate risk (95 ≤ PER < 190), considerable danger (190 ≤ PER < 380), and extremely high risk (PER ≥ 380) (Guo et al., 2010).

5.7 Feasibility of Cage Culture in the Coastal waters adjacent to St. Martin's Island

5.7.1 Cage Culture

The culture of fish in cages is a common technique for raising fish in coastal areas. The key elements that affect a cage culture system's success or failure are the site selection, water quality, season, and species choices. It also affects how much something costs to produce and how long a system will last. Due to the impracticability of regulating water quality parameters in open water cage culture systems, it is imperative to establish species-specific cultures in areas characterized by favorable water quality and consistent water exchange. Prior research on the physicochemical characteristics of water, plankton, nutrients, and heavy metals should be conducted in order to gain an understanding of the environmental/hydro-biological parameters of the site before establishing a cage culture site. This measure will aid in ensuring that the selected water body is capable of accommodating the progressively growing biological requirements resulting from cage culture operations.

5.7.2 Objective

1. To assess the environmental feasibility of cage culture in the coastal waters adjacent to Saint Martin's Island.
2. To evaluate the economic feasibility of cage culture in the coastal waters adjacent to Saint Martin's Island.
3. To create alternative job for local communities and propose recommendations regarding marine cage culture in the coastal area.

5.7.3 Material and Methods

5.7.3.a Site Selection for Cage Installation

In cage farming, the location must be carefully considered because it affects the farm's potential to make a profit. The location chosen should have the best possible water quality to prevent stress and promote maximum growth of farmed fish. It should also assure proper and secure cage installation as well as logistical and other assistance for input supply, fish harvesting, and fish sale. The location of the sea cage directly affects the operation's costs, fish mortality, output, and overall profitability. After determining the abundance, and distribution of phytoplankton, zooplankton, physicochemical properties, nutrient and heavy metal, the site for installation of cage was selected.

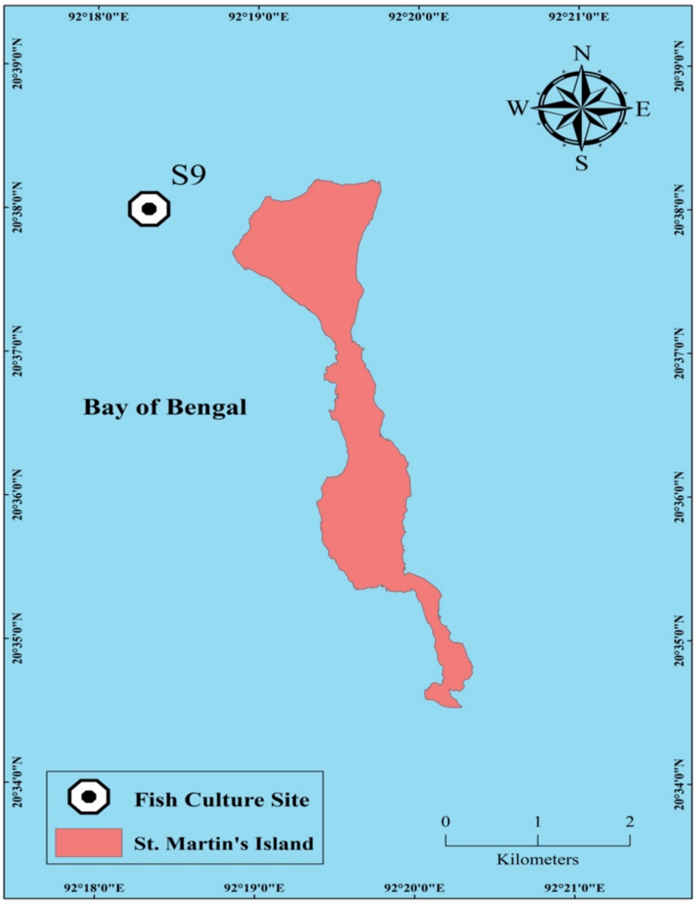


Figure 5.17 Selected site for cage installation to cultivate John's Snapper (Lutjanus johnii)

Based on abundance and distribution of physicochemical properties, nutrient, heavy metal and plankton area adjacent to station 11 was selected to cultivate herbivore fish, area adjacent to station 9 was selected to cultivate carnivore fish; and area adjacent to station 8 was selected to cultivate omnivore fish. Nevertheless, this study exclusively focused on cultivating the carnivorous species as a preliminary endeavor to assess the economic viability of cage farming for their high market demand. Based on the collected data, the beginning of the pre-monsoon hot season (March/April) was more suitable for stocking fingerling in the cage. However, in this study, January to May (the period between the cool dry winter season and the pre-monsoon hot season) was chosen for cage cultivation because all of the necessary conditions were also met during that time.

5.7.3.b Cage Construction

Factors such as water quality, depth, currents, temperature, and proximity to shore and infrastructure need to be considered for cage construction. The design of sea cages can vary depending on the species being farmed, the environmental conditions, and local regulations. Cages are typically made from sturdy materials that can withstand the corrosive effects of seawater and the forces of waves and currents. Common materials include high-density polyethylene (HDPE) pipes, nets, and steel frames. The cage structure is assembled either onshore or in a controlled area near the shore. This includes constructing the frame, attaching the netting, and ensuring proper buoyancy for the cage. The cage should be designed to withstand rough weather conditions and prevent escapes of farmed fish. High-quality netting is used to create the walls of the cage. The netting should be strong enough to contain the fish while allowing for water circulation, oxygen exchange, and waste removal. It should also be predator-resistant to protect the farmed fish from potential threats. Proper buoyancy is essential to keep the cage afloat at the desired depth. Floatation devices, such as pontoons or buoys, are attached to the cage frame. The buoyancy system should be adjustable to maintain the desired depth in changing sea conditions. One 210 cubic feet rectangular shaped floating cage were used in this study to cultivate an omnivore species. In this study iron frame floats, empty 100L plastic drams, anchors, nylon net with a 6 mm mesh, and scoop net were used for cage construction installation and harvesting process.

Fig 5.18 Cage installation for cultivating John's Snapper in the coastal waters adjacent to St. Martin's Island

Fig 5.19 Installed cage in the selected cultivation site for cultivating John's Snapper in the coastal waters adjacent to St. Martin's Island

5.7.3.c Species Selection

According to Tomascik, (1997) there are around 225 species were identified in the coastal are adjacent to St. martin's island. Depending on the criteria all the species that are found in the island will not be suitable or profitable for cage culture. A fish variety that satisfies requirements including water quality, plankton, nutrient and heavy metal abundance and distribution, marketing suitability, commercial importance, consumer acceptance, ease of culture, adaptability to the cage environment, acceptance of formula feeds, faster growth rate, and resistance to common diseases is needed for cage culture in the coastal area. Depending on the above criteria the leading fish species to culture in cage in the coastal area in Asia are follows:

Chanos chanos (Milk fish)

Lates calcarifer (Asian Sea Bass)

***Rachycentron canadum* (Cobia)**

***Seriola rivoliana & S. lalandi* (Amberjack)**

***Siganus spp* (Rabbit fish)**

***Lutjanus argentimaculatus* (Mangrove Red Snapper)**

Lutjanus erythropterus (Red Bream)

Lutjanus johnii (John's Snapper / Sea perch)

***Lutjanus sebae* (Red emperor)**

***Epinephelus spp* (Groupers)**

***Trachinotus blochii (*Asian or silver Pompano)**

***Mugil spp* (Mullet)**

Other species

A broad variety of additional species, such as threadfins, croakers, drums, gobies, scorpion fish, and others, are cultured in addition to the aforementioned species. Numerous of these species are at least sporadically produced in marine cages. Therefore, while choosing species for cage culture operations, the aforementioned traits should be carefully considered and given the utmost weight. Some of these characters might be more significant in particular regions, and as a result, in order to optimize economic benefits and preserve the long-term viability of the cultural system, it is imperative to accord more significance to the aforementioned characters within the designated locations. As per the above criteria and availability of planktons and supplementary food, suitability of physicochemical properties of seawater, nutrient and heavy metal distribution- Milk fish (*Chanos Chanos*), a planktivorous fish, John's Snapper/ John's Sea Perch (*Lutjanus johnii) and Asian Sea Bass (Lates calcarifer)*, two carnivorous fishes and*, Flathead Grey Mullet (Mugil cephalus),* an omnivorous fish was chosen as the most suitable species to be cultivated in the coastal waters adjacent to the Island. In this study Sea Perch (*Lutjanus johnii*) was taken as the representative species to assess the commercial viability of cage farming. In the course of this research, the monoculture approach to fish farming was utilized.

Selected fish species for Cage Culture in the coastal waters adjacent to St. Martin's Island

Classification of *Lutjanus johnii*

Kingdom: Animalia

Phylum: Chordata

Class: Actinopterygii

Order: Perciformes

Family: Lutjanidae

Genus: Lutjanus

Species: *Lutjanus johnii*

(Bloch, 1792)

Figure 5.20 John's Snapper/ John's Sea Perch (Lutjanus johnii)

5.7.3.d Collection of Fingerlings

The quality of fish seed plays a critical role in determining the effectiveness of cage-based grow-out cultures. In order to impede their evasion, seeds of uniform size that corresponded to the mesh dimensions of the fish net enclosure were sown. Moreover, this will facilitate the selection of an appropriate meal size for fish, mitigate feed wastage, and reduce instances of cannibalism. It is imperative that seeds possess a state of being free from diseases and defects, while also exhibiting optimal health. Typically, farmers procure fingerlings from either hatcheries or natural habitats. The investigation involved the collection of seeds from wild sources.

Figure 5.21 Length and weight measurement of fingerling of John's Snapper (Lutjanus johnii) before stocking in the cage in the coastal waters adjacent to St. Martin's Island

5.7.3.e Feeding

In cage farming, feeding rates, feeding frequency, and feeding duration are crucial considerations. The age and size of the fish affect the amount and frequency of feeding. More often feedings of a high-protein diet are required for fish larvae and fry. Fish might have lower feeding frequencies and rates as they get bigger. Fish feeding requires a lot of labor; thus, the frequency needs to be changed in a way that makes it profitable. In general, growth and feed conversion rise as feeding frequency rises. Various factors, such as the time of day, season, water temperature, dissolved oxygen levels, and other dimensions of water quality, exert an influence on the consumption of feed. In this study the cultivate fish species Jhon's Sea Perch was given only trash fish twice a day as supplementary feeds.

5.7.3.f Fish Harvesting

The act of gathering and removing fish from the environment in which they have developed and grown is referred to as harvesting. The exploitation of aquatic resources makes use of a wide range of technologies, ranging from those that are largely artisanal to those that are highly industrial. These technologies include fishing gears and procedures, as well as vessels and equipment. Fish was harvested after five months of cultivation (May, 2022).

Scoop net was used for catching fish from the net cages. After harvesting length and weight of fish were measured in cm and gm respectively.

Figure 5.22 Weight measurement of harvested John's Snapper/ Sea Perch fish after 5 months of cultivation in the coastal waters adjacent to St. Martin's Island

Figure 5.23 Length Measurement of harvested John's Snapper/Sea Perch fish after 5 months of cultivation in the coastal waters adjacent to St. Martin's Island

5.7.3.g Data Processing

Frequency distribution, range, mean, percentage, and standard deviation were utilized as statistical measures to describe the chosen explanatory and focus variables as necessary. Tables were utilized to exhibit the data in order to make it easier to understand. Additionally, some figures were utilized to clarify.

i. Calculation of Total Cost

Total Cost= Fixed Cost (FC)+ Variable Cost (VC)

= FC+VC

ii. Calculation of Length

The length of a fish is determined by the Von Bertalanffy equation. The Von Bertalanffy equation, in terms of length, is:

$L_t = L_\infty - (L_\infty - L_0)\, e^{-kt}$ ....(i)

Where,

L_t=Length of an individual at time t

L_∞= Asymptotic length of a species

L_0= Length of an individual at initial time

K= Growth coefficient

iii. Calculation of Weight

The algometric formula for weight calculation-

$W = a\, L^b$ ....(ii)

Where,

W= weight of an individual

L = length of an individual

$b = \frac{n\sum xy - \sum x \sum y}{n\sum x2 - (\sum x)^2}$

$a' = \frac{\sum y - b\sum x}{n}$

$a = 10^{a'}$

x=log [length]

y=Log [weight]

iv. Calculation of Population number

$N_t = N_0\, e^{-zt}$……………………………………………………………………………(iii)

Where,

N_t =population after t months

N_0 =initial population number

Z = instantaneous rate of total mortality

v. Calculation of Survival and Mortality rate

Survival rate (%) = $100 \times e^{-z}$ ………………………………………...(iv)

Mortality rate (%) = $100 \times (1-e^{-z})$ …………………………………….(v)

Where,

Z= Instantaneous rate of total mortality

vi. Calculation of Total Production

Total production = Average weight of an individual × Number of individuals…(vi)

vii. Calculation of Gross Return

GR=total production × per Unit price………………………………..(vii)

Where,

GR= Gross Return

viii. Calculation of Net Return

Net return = GR-TC…………………………………………………… (viii)

Where,

GR= Gross Return v, and

TC=Total Costs

ix. Calculation of Gross Margin

GM= GR-TVC………………………………………………………..(ix)

Where,

GM= Gross margin

GR= Gross return

TVC= Total variable Costs

x. <u>Calculation of Benefit Cost Ratio (BCR)</u>

BCR= GR/TC…………………………………………………………..(x)

Where,

GR= Gross return and,

TC= Total costs

Economic Feasibility Test:

If the value of **BCR > 1** means the cultivation of the species is economically feasible

If the value of **BCR < 1** means the cultivation of the species is not economically feasible.

If the value of **BCR =1** which indicates the Break-Even Point means neither feasible nor unfeasible.

5.8 Feasibility of Seaweed Culture in Coastal waters adjacent to St. Martin's Island

5.8.1 Seaweed Culture

The seaweed sector offers a diverse range of products with an approximate annual value ranging from US$ 5.5-6 billion. Food products intended for human consumption make a significant contribution of approximately US$ 5 billion to this total. A significant portion of the remaining billion dollars is attributed to hydrocolloids, which are substances derived from seaweeds. The remaining portion consists of lesser applications, including but not limited to fertilizers and additives for animal feed. The seaweed business consumes an estimated yearly quantity of 7.5-8 million tonnes of wet seaweed. The seaweed used in this context is sourced either from naturally occurring (wild) populations or from intentionally grown (farmed) crops. The cultivation of seaweed has experienced significant growth due to an increasing demand that surpasses the supply derived from natural sources. Commercial harvesting is conducted in over 35 nations, distributed across both the Northern and Southern Hemispheres. These countries use marine resources in a variety of water temperatures, ranging from cold to temperate and tropical regions.

5.8.2 Objective

1. To assess the environmental feasibility of seaweed culture in the coastal waters adjacent to Saint Martin’s Island.
2. To evaluate the economic feasibility of seaweed culture in the coastal waters adjacent to Saint Martin’s Island.
3. To establish alternative employment opportunities for local residents and provide suggestions pertaining to the practice of marine seaweed culture in coastal regions

5.8.3 Materials and Methods

5.8.3.a Site Selection

Depending on the data of water parameter described in result and discussion section of Pre-monsoon Hot Season, Monsoon and Cool Winter season of 2020 and 2021, and nutrient and heavy metal concentration during Pre-monsoon Hot Season 2020 and Cool Winter season, 2021, Cool Winter season (January, 2022) was selected to implant the seaweeds for cultivation as all the suitable properties needed for seaweed culture was found during that time but pre-monsoon season could also be considered for seaweed culture. According to the findings of the study, it would be possible to cultivate seaweed in the coastal water close to St. Martin's Island from the months of October through April. Depending on distribution of physicochemical properties, nutrients and heavy metals area near sampling station 1 was selected as the most suitable station but station 10 and 12 could also be considered.

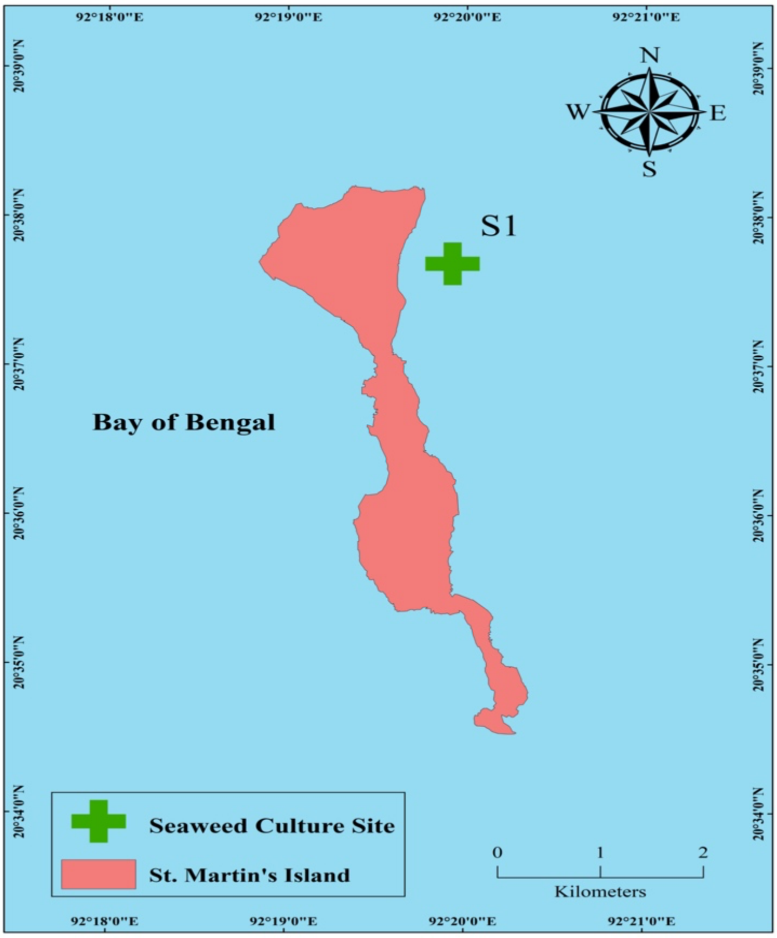


Figure 5.24 Selected site to cultivate seaweed in the coastal waters adjacent to St. Martin's Island.

Figure 5.25 Seaweed Culture as a pilot project in coastal waters adjacent to St. Martin's Island

5.8.3.b Seaweed Selection

Seaweeds are prevalent in the littoral and sublittoral zones of St. Martin's Island, located in Bangladesh. Bangladesh's southernmost territory is this island. The Island has a diverse range of red, brown, and green seaweeds. According to Aftab (2019) 29 species of green (*Chlorophyta*), 43 species of brown (*Phaeophyta*) and 78 species of red (*Rhodophyta*) seaweed found in the in the Island. Most of the species available in the island have economic value. After analysis of all the gathered data it was decided that the following species of seaweed could be cultivated in the coastal water adjacent to St. martin’s Island.

- ***Caulerpa sertularioides***
- ***Caulerpa racemosa***
- ***Entermorpha sp.***
- ***Hydroclathrus clathretus***
- ***Sargassum polycystum***
- ***Sargassum tuliformes***
- ***Sargassum illifolium***
- ***Gelidiella tenuissima***
- ***Ulva intestinalis***
- ***Ulva lactuca***
- ***Helimenia discoidea***
- ***Hypnea valentiae***
- ***Hypea pannosa***
- ***Gelidium pusillum***
- ***Gracilaria longifolia***
- ***Gracilaria gracilis***
- ***Padina gymnospora***

Depending on all the physicochemical properties of the water, nutrient distribution, heavy metal distribution, commercial importance and availability of the species *Ulva intestinalis* (Green algae*), Gracilaria gracilis* (Red algae) and *Padina gymnospora* (Brown algae) were selected as the most suitable species for cultivation in the coastal water adjacent to St. martin’s Island. In this study, *Padina gymnospora* was selected as a representative species to assess the economic viability of seaweed cultivation on the island.

Selected species of seaweed to cultivate in the coastal waters adjacent to St. Martin's Island and it's use

- **Classification of *Padina gymnospora***

Kingdom: Chromista
Phylum: Gyrista
Class: Phaeophyceae
Order: Dictyotales
Family: Dictyotaceae
Genus: *Padina*
Species: *Padina gymnospora*
(Sonder, 1871)

***Figure 5.26 Padina gymnospora* (Brown Algae)**

Use of *Padina gymnospora*: It is a species of brown algae commonly found in tropical and subtropical regions. It has several uses, including:

- Food: It is used as a food source in some parts of the world. It is often consumed fresh or dried, and is used in soups, stews, and salads.
- Medicine: It contains several bioactive compounds that have been shown to have medicinal properties. For example, it has been used to treat diabetes, high blood pressure, and inflammation.
- Cosmetics: It is a component of skin care products used in the cosmetics industry. It can assist improve the skin's look and contains hydrating and anti-aging qualities.

- Agriculture: Additionally, it is utilized in agriculture as a soil improver and fertilizer. It is abundant in nutrients including potassium, nitrogen, and phosphorus, which are crucial for plant growth.
- Bioremediation: It is used in bioremediation, which is the process of using organisms to remove pollutants from the environment. It has been shown to be effective at removing heavy metals and other pollutants from water.

5.8.3.c Seedlings Collection

The seaweed seedlings were obtained from the southern part of Cox's Bazar. This resource serves as an excellent means of gathering a variety of seaweed species. The occurrence of these species is also evident on St. Martin's Island. Nonetheless, the procurement of marine algae seeds in this region presents notable difficulties as a result of the harsh conditions marked by a continually robust and formidable tidal current. The seeds were collected and afterwards stored within a seeds aquarium located at the Bangladesh Oceanographic Research Institute (BORI). A continuous circulation of seawater was established within the aquarium in order to establish optimal conditions for the preservation of seaweed seeds. Following a 24-hour preservation period, the seeds were subsequently transported to St. Martin's Island using an icebox for the purpose of growing.

5.8.3.d Instruments Needed for Growing Seaweed

The following items are necessary for the cultivation of seaweed: Lakkha Fish Net (utilized for the Floting Net Method), White Rope (8mm) (employed for the Long Line Method), Bobin Thread (utilized for Seaweed Seed Attachment), Bamboo (utilized for the Long Line Method), Aquatic Seaweed Seed (Species: *Padina gymnospora*), Multimeter (utilized for the measurement of water parameters at the culture site), Signal Light (utilized for area identification), Fishing Buoy (employed for floating the rope), Weight Machine (utilized for measuring the quantity of seaweed), and Measuring Tape (utilized for measuring the total length of the seaweed). In order to facilitate seaweed culture, the utilization of a chopper for cutting bamboo and scissors for cutting the rope and bobbin thread was deemed necessary.

5.8.3.e Sampling Approach

The aim of this study is to evaluate the suitability of cultivating commercially important seaweed species that have both edible and economic significance. The selection of St. Martin's Island, Bangladesh as the location for this study project is based on several considerations. These aspects include its near proximity to coastal areas, the availability of abundant resources for seaweed farming, suitable weather conditions, and the cost-effectiveness and accessibility of manpower. The selection of this specific site is predicated upon its geographical characteristics, which render it highly noteworthy and auspicious for the cultivation of seaweed.

5.8.3.f Data Collection:

The study was conducted over a duration of two months, commencing in January 2022. Primary data was collected through the utilization of field surveys. The validity of the secondary data was also confirmed using this information. Primary data was collected using a combination of survey methodologies. Data pertaining to the practice of cultivating seaweed, including its merits and drawbacks, was procured from a variety of scholarly sources such as papers, journals, reputable governmental and non-governmental entities, research establishments, and academic institutions..

5.8.4 Seaweed Culture Method

Attaching seaweed seedling to rope lines or nets floating in the water is the simplest and most used form of seaweed farming. These two methods are named as-

a. Long Line method
b. Floating Net Method

5.8.4.a Long Line Method

Padina gymnospora (Brown algae) were selected for cultivation through long line method. Six long lines were installed to culture these seaweeds. The length of per line was about 40 ft nylon rope (8mm). The distance between each line was measured to be 2 feet, resulting in a total width of the area equal to 12 feet. The amount of seaweed seedlings planted in each rope was 350 gm for ***Padina gymnospora***. The total amount of seaweed seedlings planted was 2100 gm. For attachment every seedling with the rope, the bobbin thread is used. Each bamboo pole was around 6 feet in height.

Figure 5.27 Selected area to cultivate Padina gymnospora using long line method in the coastal waters adjacent to St. Martin's Island

The inter-seedling spacing along the rope measures approximately 5 inches. The spacing between each line measured approximately two feet. Subsequently, three fishing buoys were affixed to each line for the purpose of flotation. In order to facilitate nighttime navigation and protect the region from potential disruptions, a set of four signal lights were employed as navigation aids, enabling other boaters to readily discern the vicinity. A signboard was further installed to raise awareness among the local populace on the practice of seaweed cultivation.

Figure 5.28 Cultivated Padina gymnospora after 25 days in the cultivation facilities using long line method

5.8.4.b Floating Net Method

Globally, seaweed cultivation employs a nylon net with a mesh size of 40 cm, which is stretched to a width of 2.5 meters and a length of 5 meters. The net is typically fabricated utilizing either nylon rope or stranded polyethylene wires, and the mesh structure is built using test lines. The corners of the object, which possess loops, are affixed to either poles or wire that is stretched between the posts. The floating net farming technology offers the advantage of increased production due to the potential for greater seaweed growth in a specific space.

Figure 5.29 Selected area to cultivate Padina gymnospora using floating net method in the coastal waters adjacent to St. Martin's Island

In this study, the floating net culture method, Lakkha fish nets were used with dimensions of 40 ft in length and 12 ft in width. The mesh size measures around 20 centimeters. The net was constructed using either nylon rope or stranded polyethylene wires with a test strength ranging from 110 to 150 lbs. The mesh work of the net was composed of lines with a test strength ranging from 30 to 100 lbs. The net was placed horizontally. The interconnection of all the seaweed seedlings was facilitated through the utilization of bobbin thread within this net. The quantity of ***Padina gymnospora*** seedlings was around 3000 grams. The net is positioned at a height of 2.0 feet above the ground level. A total of fifteen fishing buoys were employed to facilitate the buoyancy of the net.

5.8.5 Seaweed Harvesting

Pruning is a horticultural technique employed to harvest plants by systematically traversing the designated area in a row-by-row manner. In this investigation, the branches of each seaweed specimen were severed using a knife. Scoop nets were employed for the purpose of collecting harvested seaweed. The weight and length measurements were obtained for all harvested weeds prior to their dispersion for drying, and the recorded data were retained for future reference.

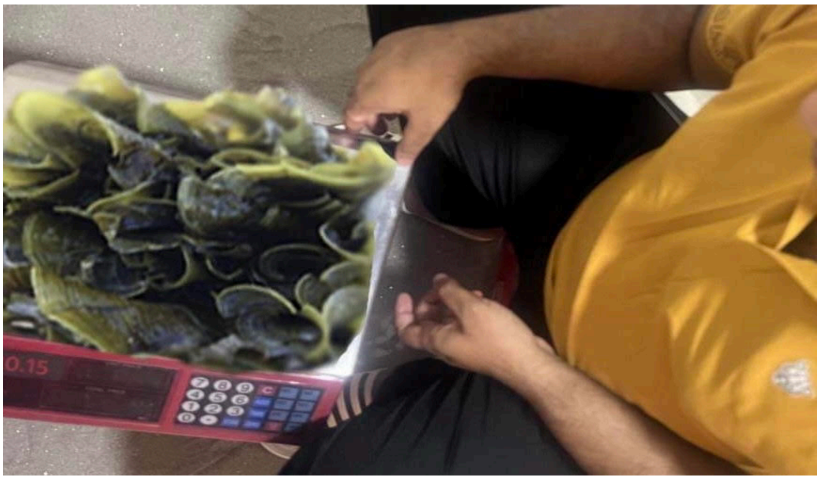


Figure 5.30 Weight measurement of Padina gymnospora after 30 days of cultivation in the coastal waters adjacent to St. Martin's Island

5.8.6 Data Processing

Statistical metrics such as frequency distribution, range, mean, percentage, and standard deviation were employed to describe the selected explanatory and focal variables, as deemed appropriate. Tables were employed to present the data in a manner that facilitates comprehension. Moreover, certain figures were employed for the purpose of elucidation.

Chapter 6 **Results**

6.1 Seasonal Variation and Spatial Distribution of Physicochemical Properties of the Coastal water of St. Martin's Island

During the course of the research, measurements of temperature, salinity, hydrogen power (pH), dissolved oxygen (DO), electric conductivity (EC), total dissolved solids (TDS), and transparency were taken at a total of twelve distinct locations over the course of three different seasons: pre-monsoon, monsoon, and chilly winter season, 2019-2021.

6.1.1 Seasonal Variation and Spatial Distribution of Temperature

Temperature influences the chemical and biological activities of marine organisms. Moreover, the growth rate of seaweeds is dependent on the temperature of the coastal waters. Temperature also regulates other factors such as pH, conductivity, and DO. The temperature of coastal water was observed over 12 stations in three different seasons. The average temperature from the stations ranged from 24.16ºC to 27.4ºC (Figure 6.1). Mean seasonal temperature for the pre-monsoon, monsoon and dry cool winter seasons are respectively 26.83±0.21ºC, 27.06±0.22ºC, and 24.61±0.39ºC respectively (Table 6.1). The maximum temperature during the pre-monsoon and rainy monsoon season was observed in the western region of the island while in the dry cool winter season, the maximum temperature was measured in the northern waters of the island (Figure 6.2).

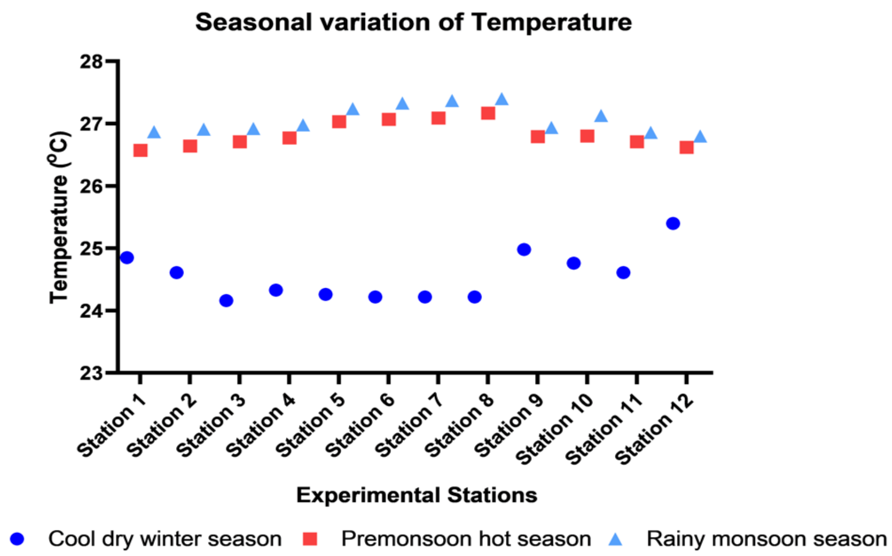


Figure 6.1 Seasonal variation of Temperature in the coastal waters of St. Martin's Island

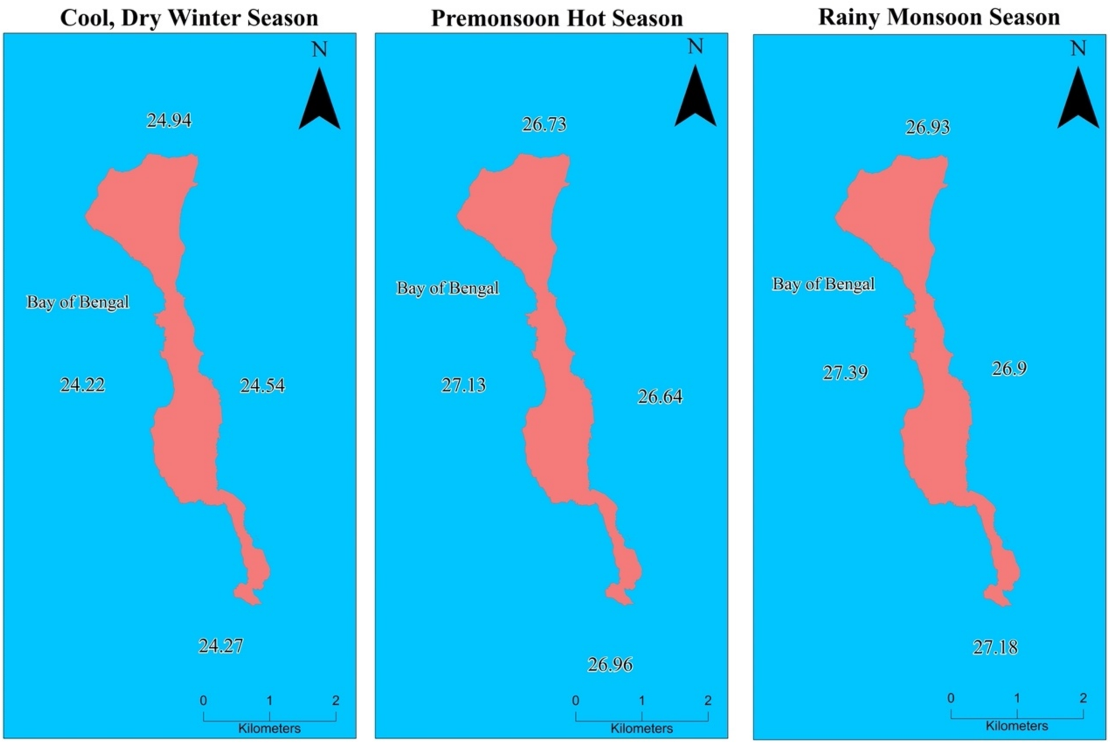


Figure 6.2 Spatial distribution of Temperature in the coastal waters of St. Martin's Island

6.1.2 Seasonal Variation and Spatial Distribution of Salinity

Seawater salinity is a highly valuable factor in the production of seaweed because it is one of the primary determinants of osmotic equilibrium. It is also a key component that greatly affects the abundance and distribution of organisms in marine environments. The salinity of the coastal water around St. Martin's Island ranged from 24.42 psu to 33.76 psu (Figure 6.3). The highest seasonal salinity value was 32.91±0.51 psu in the pre-monsoon season, and the lowest in monsoon season 24.43±0.38 (Table 6.1). The maximum salinity during the pre-monsoon and monsoon season was observed in the southern waters while in the dry cool winter season northern waters of the island. The minimum salinity was recorded in the waters east of the island while during the dry cool winter season waters in the south of the island had the minimum salinity (Figure 6.4).

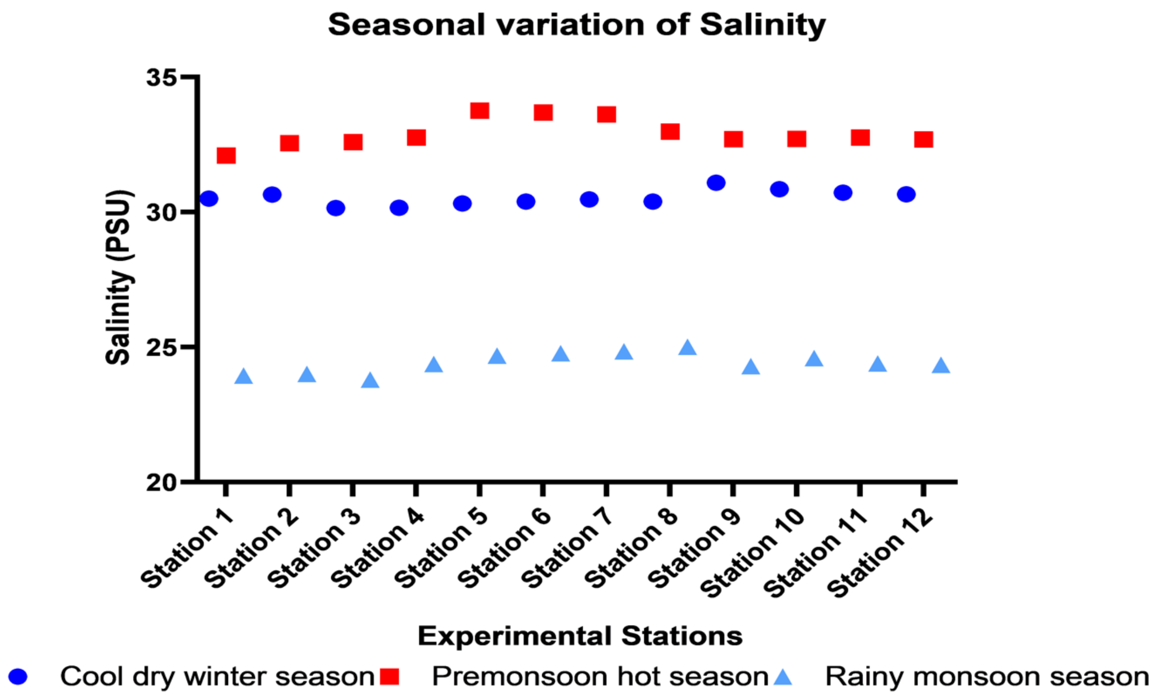


Figure 6.3 Seasonal variation of Salinity in the coastal waters of St. Martin's Island

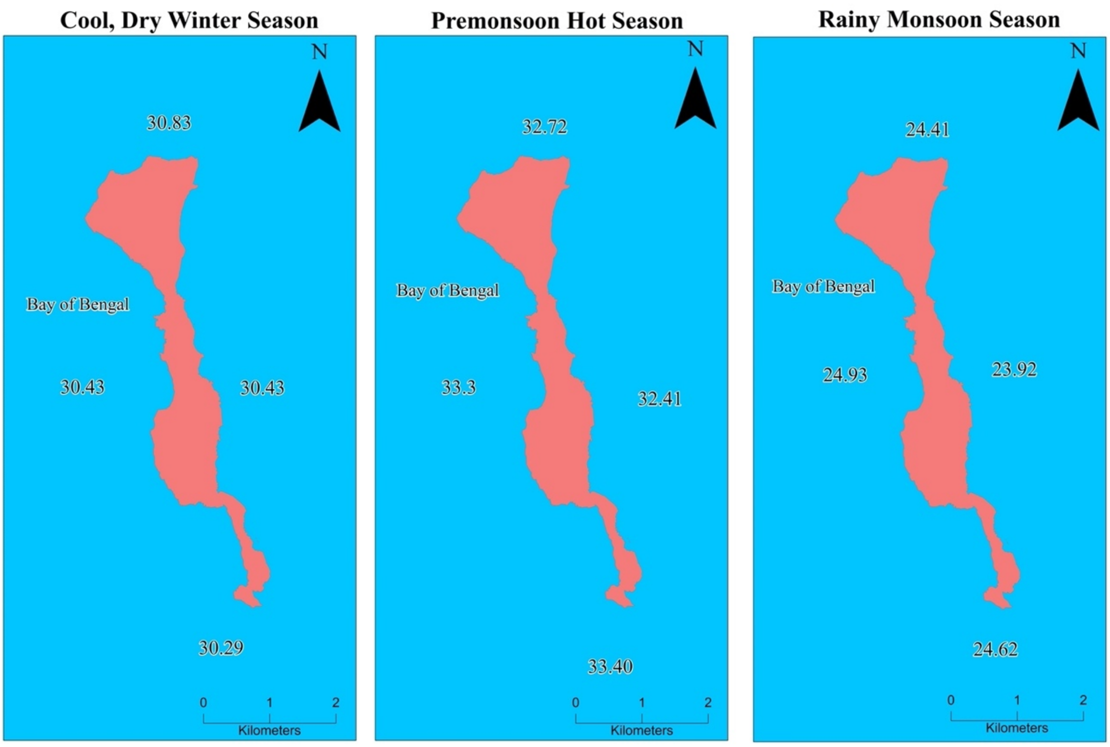


Figure 6.4 Spatial distribution of Salinity in the coastal waters of St. Martin's Island

6.1.3 Seasonal Variation and Spatial Distribution of pH

The value of pH measures the concentration of hydrogen ions in a solution and indicates the intensity of acidity or alkalinity. Almost all metabolic activities of aquatic organisms are pH-dependent. The pH value of seawater ranged from 7.71 to 8.22 (Figure 6.5). The maximum pH was measured at St-9 in pre-monsoon season and the minimum pH is found at St-12 in monsoon season. Mean seasonal pH for pre-monsoon, monsoon and dry cool winter seasons are 8.18±0.02, 7.80±0.06, 8.13±0.02 respectively (Table 6.1). The value of pH is almost equal at every side of the island in different seasons (Figure 6.6).

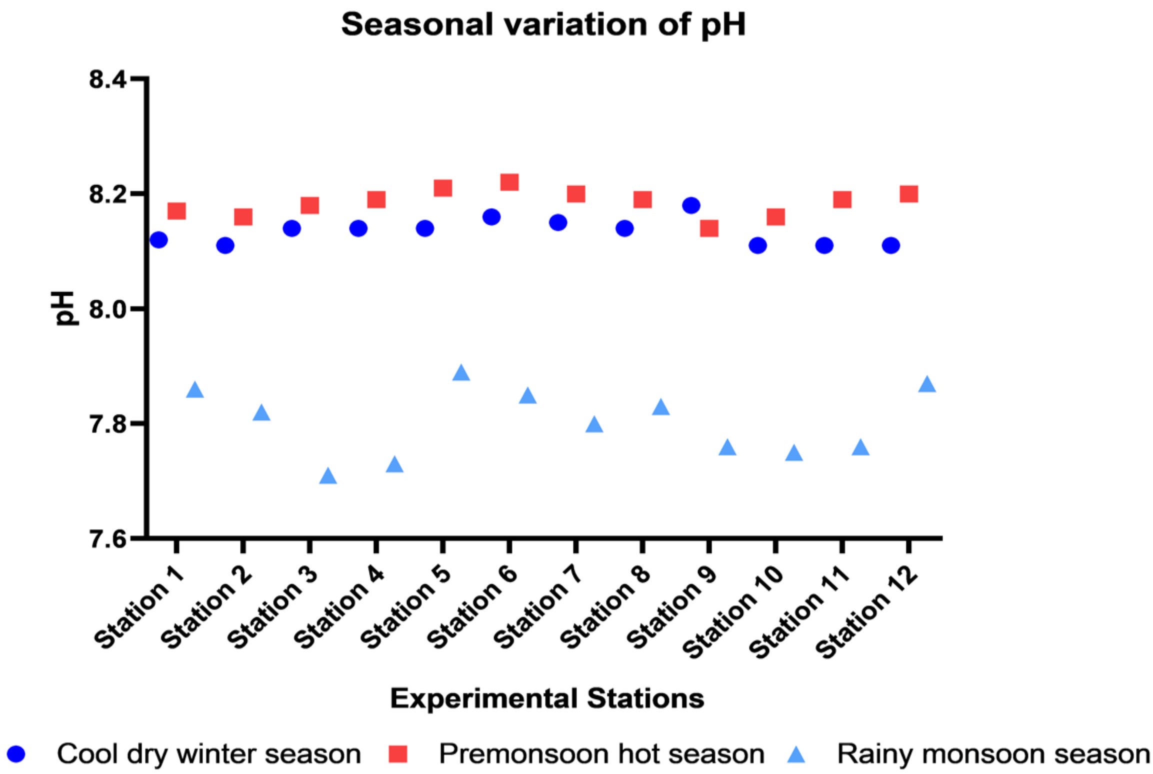


Figure 6.5 Seasonal variation of pH in the coastal waters of St. Martin's Island

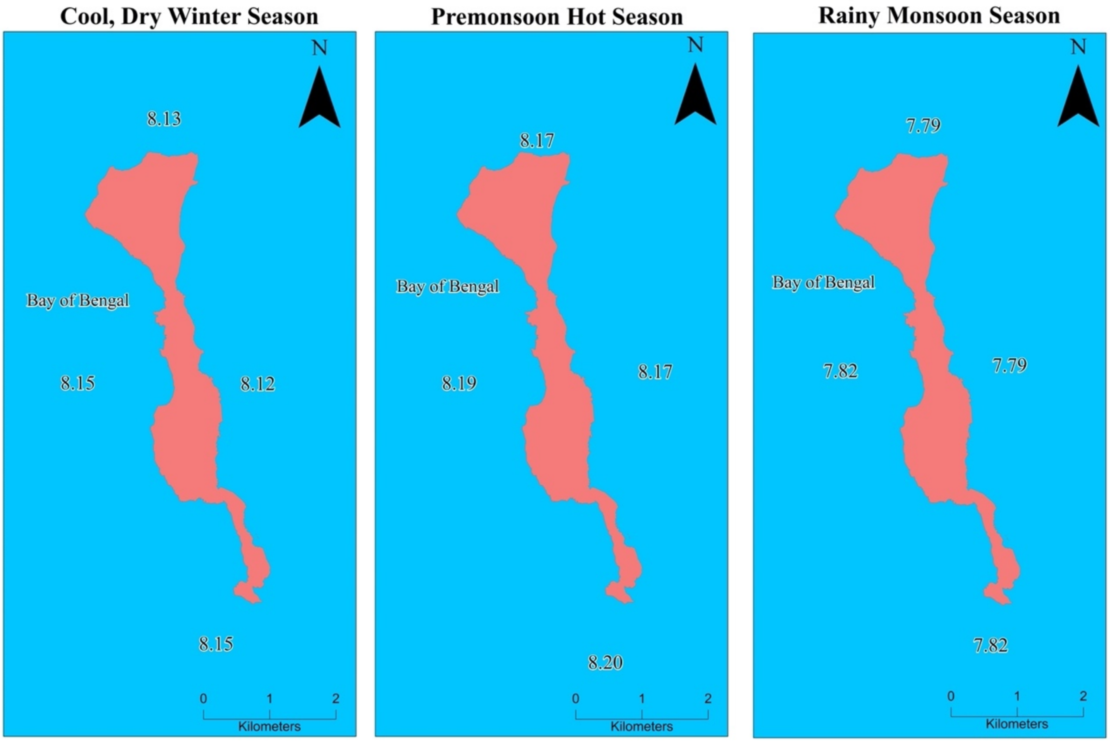


Figure 6.6 Spatial distribution of pH in the coastal waters of St. Martin's Island

6.1.4 Seasonal Variation and Spatial Distribution of Dissolved Oxygen (DO)

The concentration of dissolved oxygen dictates whether the biological changes in the marine environment are the result of aerobic or anaerobic organisms. The two sources of oxygen in water are the atmosphere and photosynthetic organisms. The depletion of oxygen typically arises from various sources, including the respiratory activities of marine creatures, the decomposition of organic matter, elevated temperatures, and the release of oxygen-consuming waste materials (Singh et al., 2012). During the study, a higher concentration of dissolved oxygen is observed during the winter season in respect to the other two seasons. This concentration of oxygen could be lower due to the higher salinity and temperature of the water during the pre-monsoon season. The concentration of oxygen in the study area ranged from 4.82 to 6.74 mg/L ppm (Figure 6.7). The mean seasonal value of DO for the three seasons are respectively 5.95±0.06 ppm,4.96±0.09 ppm and 6.47±0.21 ppm (Table 6.1). During the study, the highest concentration of DO were measured in the western, eastern and southern waters around the island during the pre-monsoon hot season, rainy monsoon season and dry cool winter season respectively (Figure 6.8).

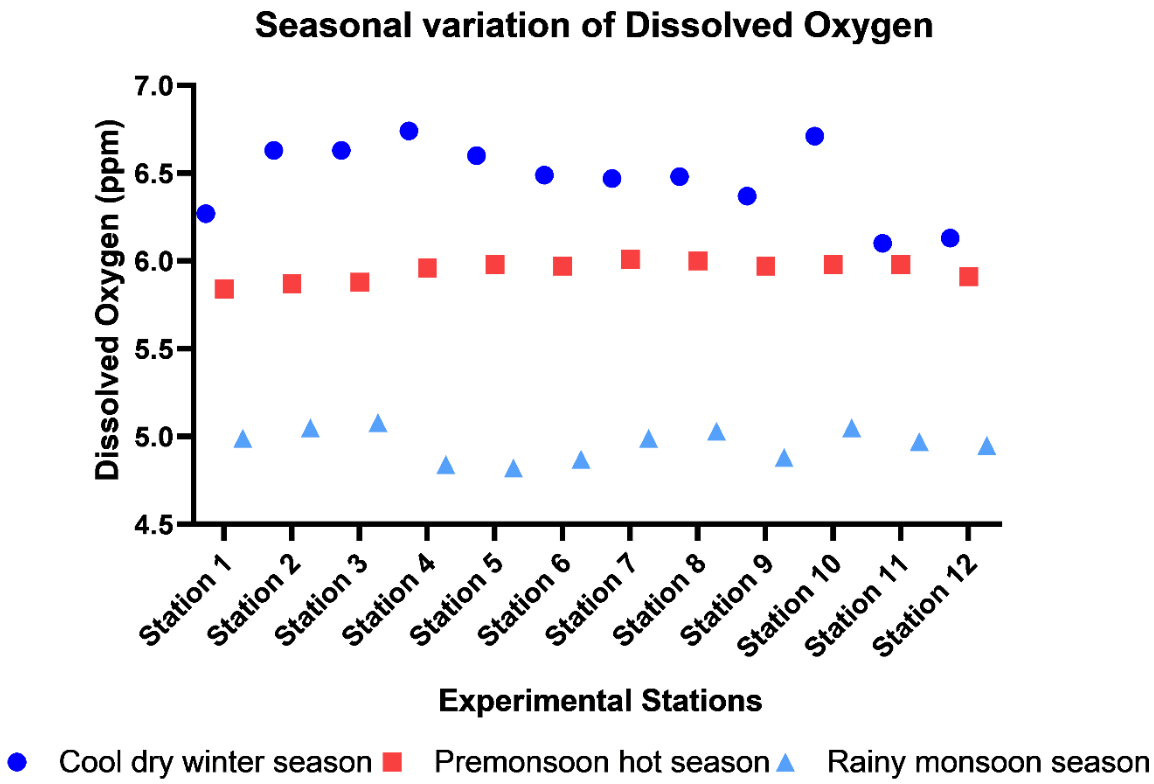


Figure 6.7 Seasonal variation of DO in the coastal waters of St. Martin's Island

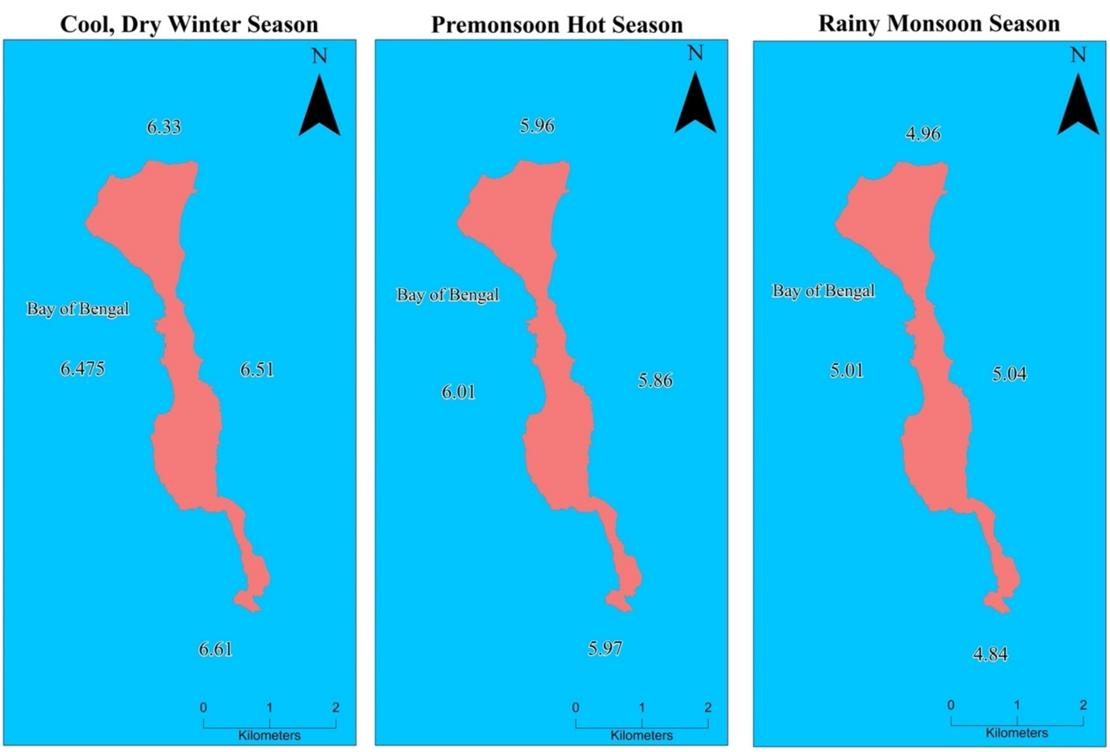


Figure 6.8 Spatial distribution of DO in the coastal waters of St. Martin's Island

6.1.5 Seasonal Variation and Spatial Distribution of Electrical Conductivity (EC)

Water quality is reflected in the EC value, which indicates the concentration of ions and nutrients in the water (DeZuane, 1997). It relies on the nutrition and its ion concentrations. In the study, the value of EC of seawater ranged from 39.0 mS/cm to 53.46 mS/cm (Figure 6.9). The mean seasonal EC for pre-monsoon, monsoon and dry cool winter are respectively 52.06±0.90 mS/cm, 40.07±0.76 mS/cm, 46.61±0.72 mS/cm (Table 6.1). Due to high salinity in the pre-monsoon hot season, high EC is found on the south side of St Martin Island. The minimum value of EC was found on the east side in the rainy monsoon season (Figure 6.10).

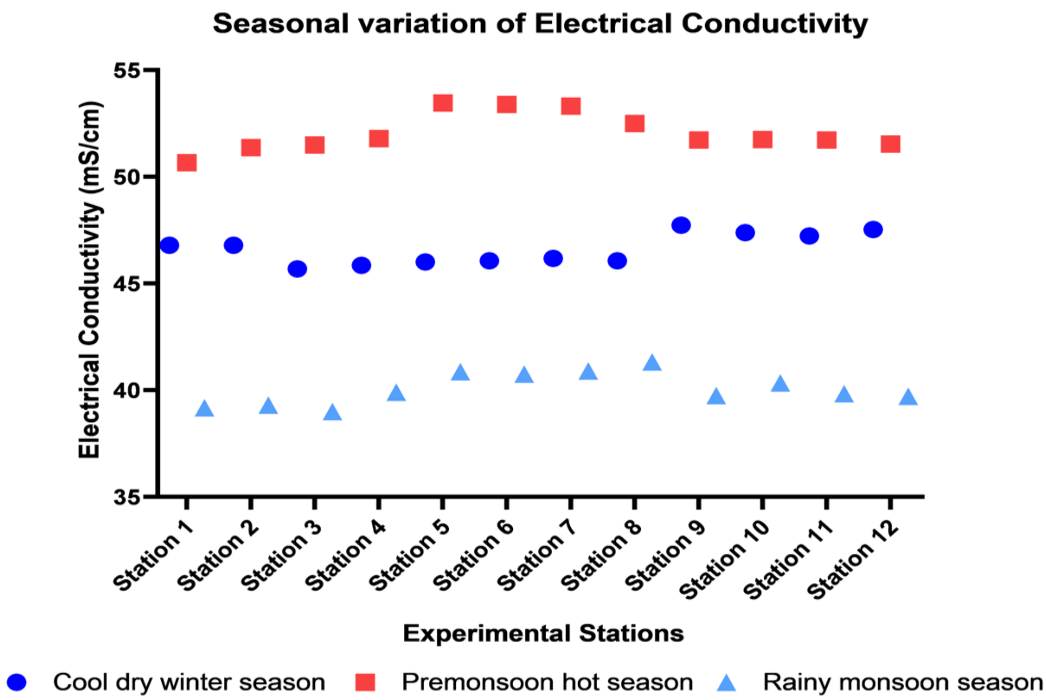


Figure 6.9 Seasonal variation of EC in the coastal waters of St. Martin's Island

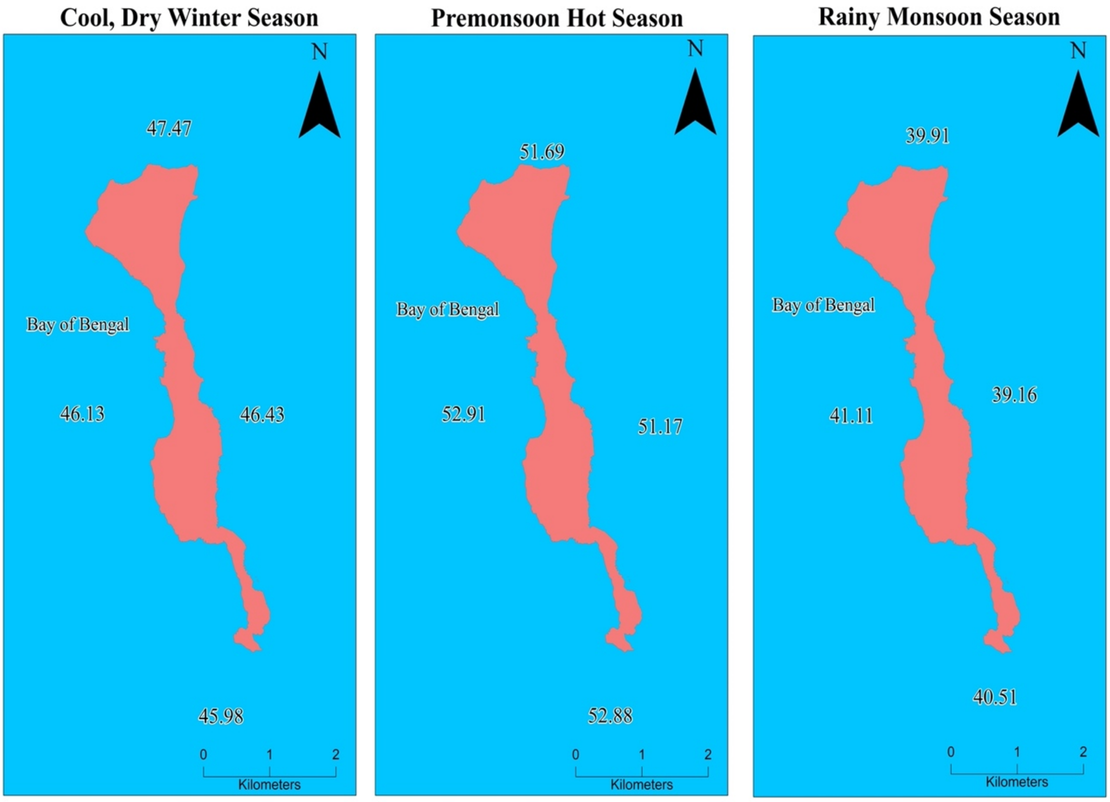


Figure 6.10 Spatial distribution of EC in the coastal waters of St. Martin's Island

6.1.6 Seasonal Variation and Spatial Distribution of Total Dissolved Solids (TDS)

The values of TDS signify the quantity of inorganic chemicals present in a water sample (Kumar & Prabhahar, 2012). The value of TDS ranged from 20.35 to 27.9 g/l, (Figure 6.11). The maximum value of TDS was found at St-3 in pre-monsoon season and the minimum TDS is found at St-5 in monsoon season. The average seasonal variation of TDS for the pre-monsoon hot season, rainy monsoon season and dry cool winter season are 27.51±0.23 g/l, 20.98±0.35 g/l, and 26.33±0.25 g/l respectively (Table 6.1). The maximum value of TDS during the pre-monsoon and monsoon season was observed in the western and southern waters while in the dry cool winter season northern waters of the island (Figure 6.12).

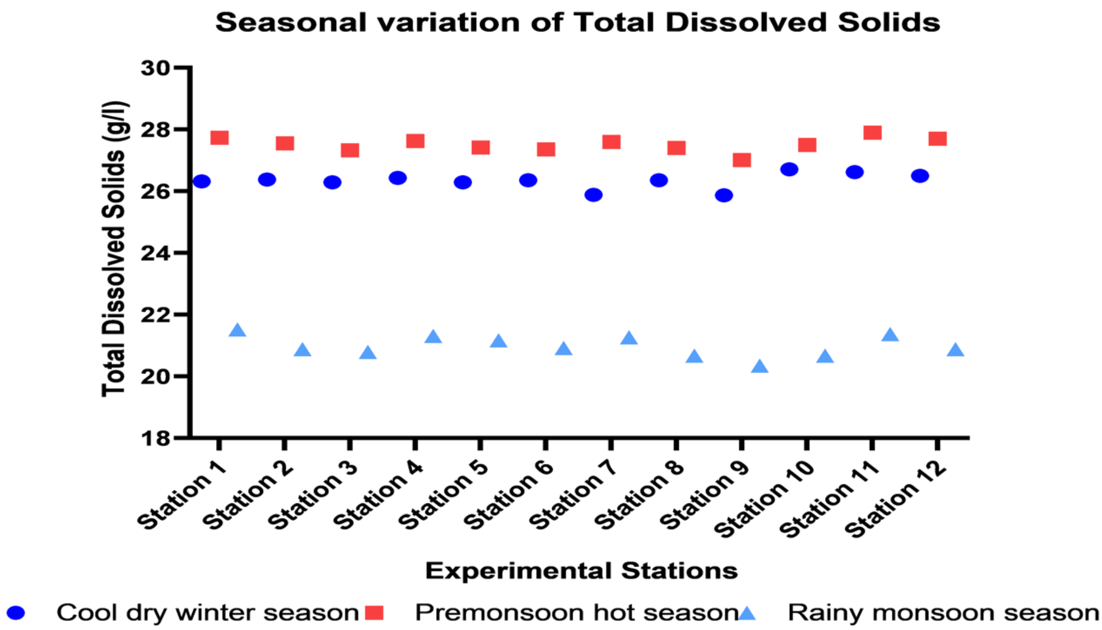


Figure 6.11 Seasonal variation of TDS in the coastal waters of St. Martin's Island

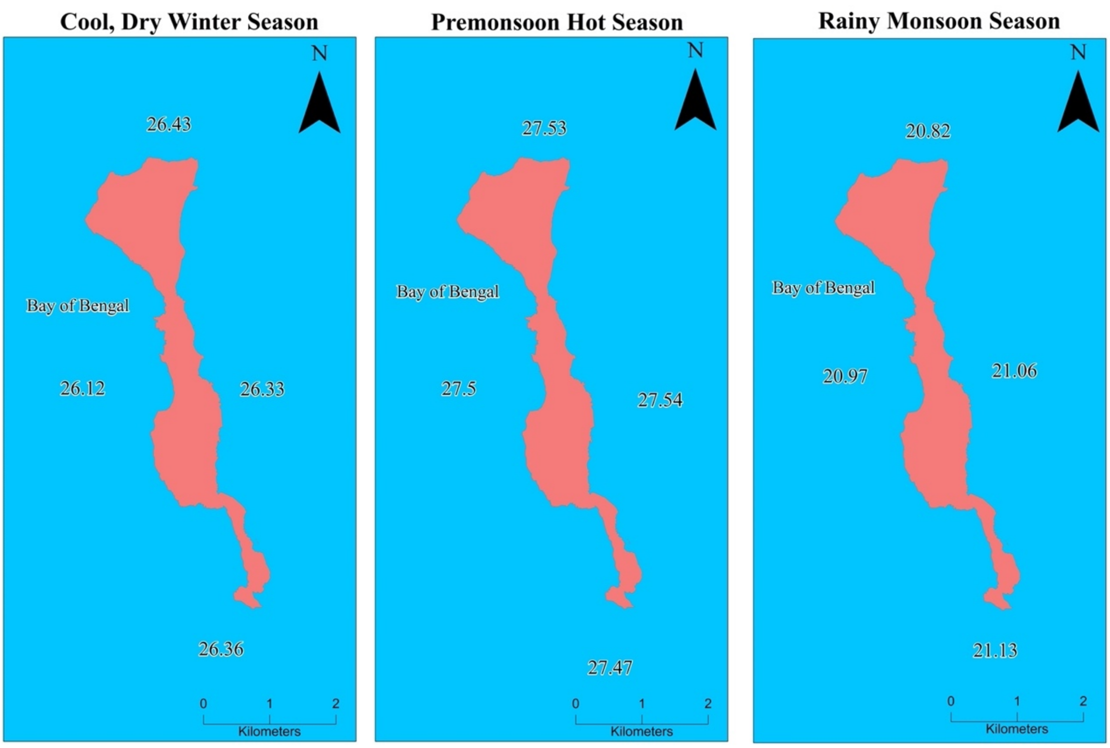


Figure 6.12 Spatial distribution of TDS in the coastal waters of St. Martin's Island

6.1.7 Seasonal Variation and Spatial Distribution of Transparency

The transparency of water is a measure of its clarity. It is important to quantify this parameter as it indicates the depth of sunlight penetration and sunlight is essential for photosynthesis. Transparency of the water around St. Martin's Island ranged from 1.42 m to 4.16 m (Figure 6.13). The transparency of the water was observed to be higher during the dry cool winter season due to the calm environment than in other seasons. The mean seasonal variation of transparency for pre-monsoon, monsoon and dry cool winter are 2.68 ± 0.02 m, 1.45 ± 0.03 m and 4.14 ± 0.02 m respectively (Table 6.1). The highest value of transparency during the pre-monsoon and monsoon seasons was measured in the seawater on the south and north side of the island while in the winter season the water was more transparent in the south side of the island (Figure 6.14).

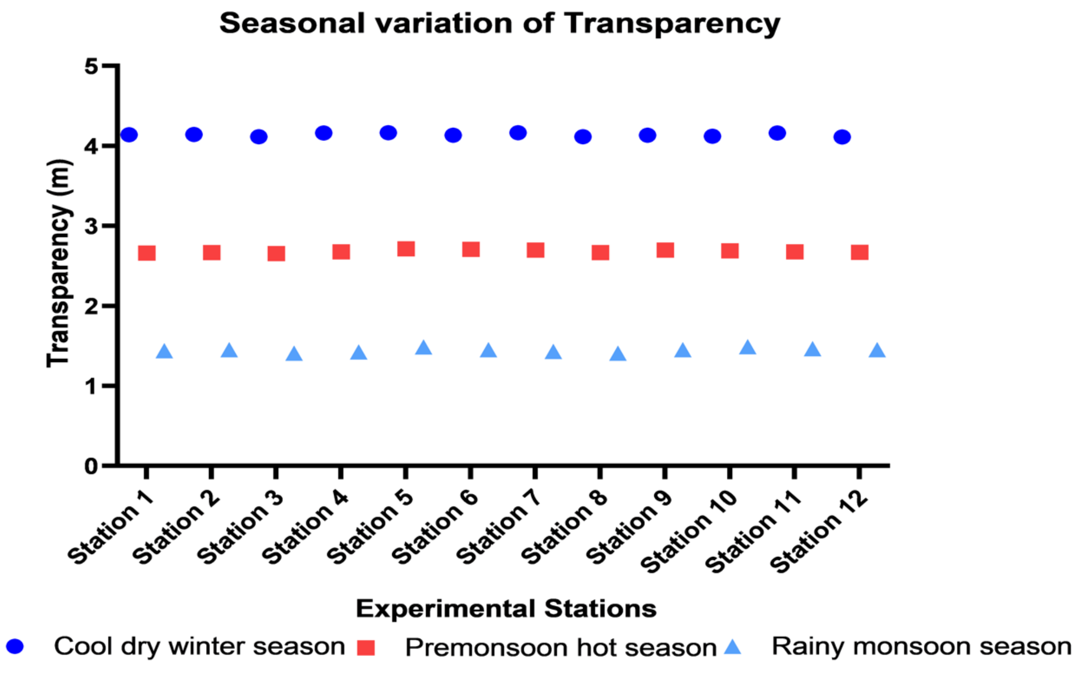


Figure 6.13 Seasonal variation of Transparency in the coastal waters of St. Martin's Island

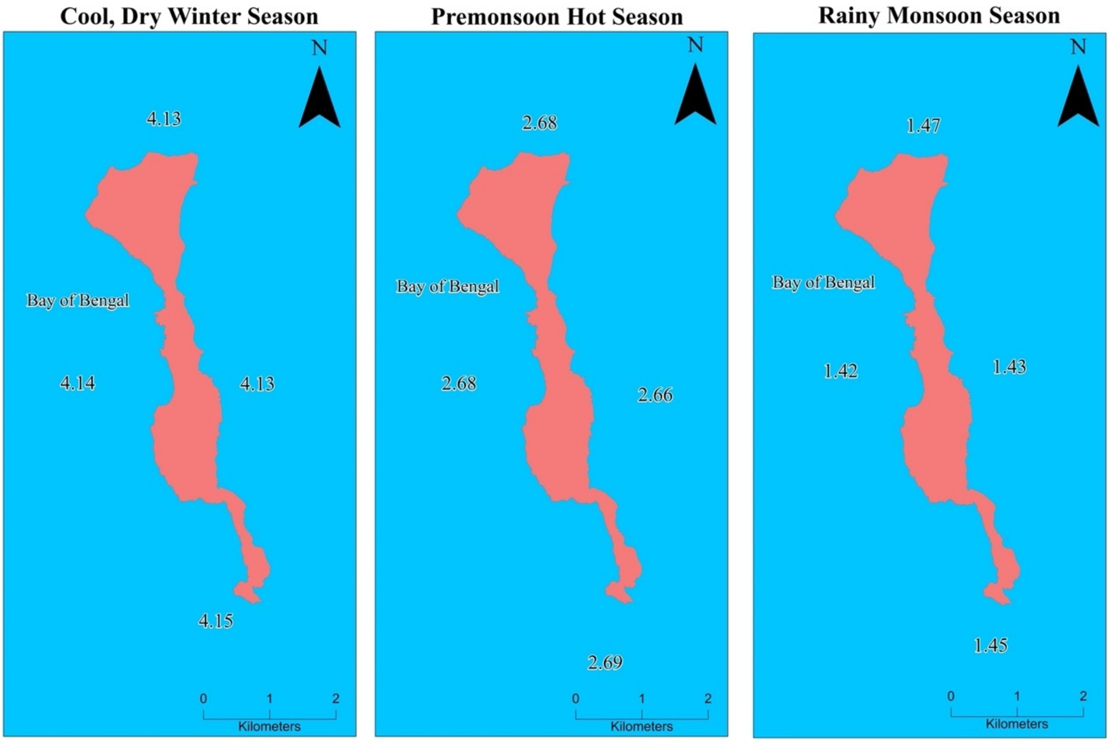


Figure 6.14 Spatial distribution of Transparency in the coastal waters of St. Martin's Island

During the study, the physicochemical properties of the coastal waters around the island (north, south, east and west) was observed. However, based on the findings of this investigation, it was not possible to pinpoint a single cause that is responsible for the variations in the values of the physicochemical parameters found throughout the island.

Table 6.1 Mean values and standard deviation of physicochemical properties

Season	Temperature	Salinity	pH	DO	EC	TDS	Transparency
Pre-Monsoon hot season	26.83 ± 0.21	32.91 ± 0.51	8.18 ± 0.02	5.95 ± 0.06	52.06 ± 0.90	27.51± 0.23	2.68 ± 0.02
Rainy Monsoon Season	27.06± 0.22	24.43 ± 0.38	7.80 ± 0.06	4.96 ± 0.09	40.07 ± 0.76	20.98± 0.35	1.45 ± 0.03
Dry cool winter season	24.55± 0.39	30.53 ± 0.28	8.13 ± 0.02	6.47 ± 0.21	46.61 ± 0.72	26.33± 0.25	4.14 ± 0.02

6.2 Abundance, Diversity and Distribution of Plankton in the Coastal waters adjacent to St. Martin’s Island

Investigation was carried out on cool dry winter season, 2019 and pre monsoon hot season 2020 in the adjacent sea areas of St. Martin's Island to assess the species composition and horizontal distribution of phytoplankton and zooplankton community in St. Martin's Island related to biophysical parameters for the first time. Phytoplankton is the foundation of the food web and plays a critical role in the sea and coastal food web dynamics. Phytoplankton accounts for over 90% of total output in the marine ecosystem and contributes to primary production by serving as the foundation of the food web, as well as supporting commercial fisheries in the marine and coastal environment. The taxonomic composition and dominance of zooplankton are similarly influenced by phytoplankton organization. Many species that feed on phytoplankton make up the majority of zooplankton groupings. Zooplankton grazers can reduce phytoplankton density dramatically. For example, at a 20% grazing rate, zooplankton can reduce phytoplankton populations by around 75% (Dawes, 1998). Both zooplankton and phytoplankton are important components of the marine ecosystem and act as indicators of water quality since minor change in their environment might have a significant impact on them. Temperature and acidity changes, as well as an increase in nutrients from farm runoff and pollution, can all have a significant impact on plankton. Changes in plankton can often provide early warning indications of an environmental hazard. Physical processes such as mixing of water masses, light, temperature, turbulence, and salinity, as well as chemical components such as nutrients, are the most important environmental factors that regulate phytoplankton community formation.

6.2.1 Phytoplankton’s Abundance, Diversity and Distribution in the Coastal waters of St. Martin’s Island

The sampling locations were visited during the pre-monsoon hot season, the rainy monsoon season, and the cool, dry winter season. However, as mariculture cannot be done in the rainy monsoon season due to the unstable weather condition the phytoplankton sample was only collected during the pre-monsoon hot season and cool, dry winter season. The seasonal variation data of the abundance, diversity and distribution of phytoplankton will help us to determine the suitable season and location to cultivate fish in cage in the coastal waters of St. Martin’s Island.

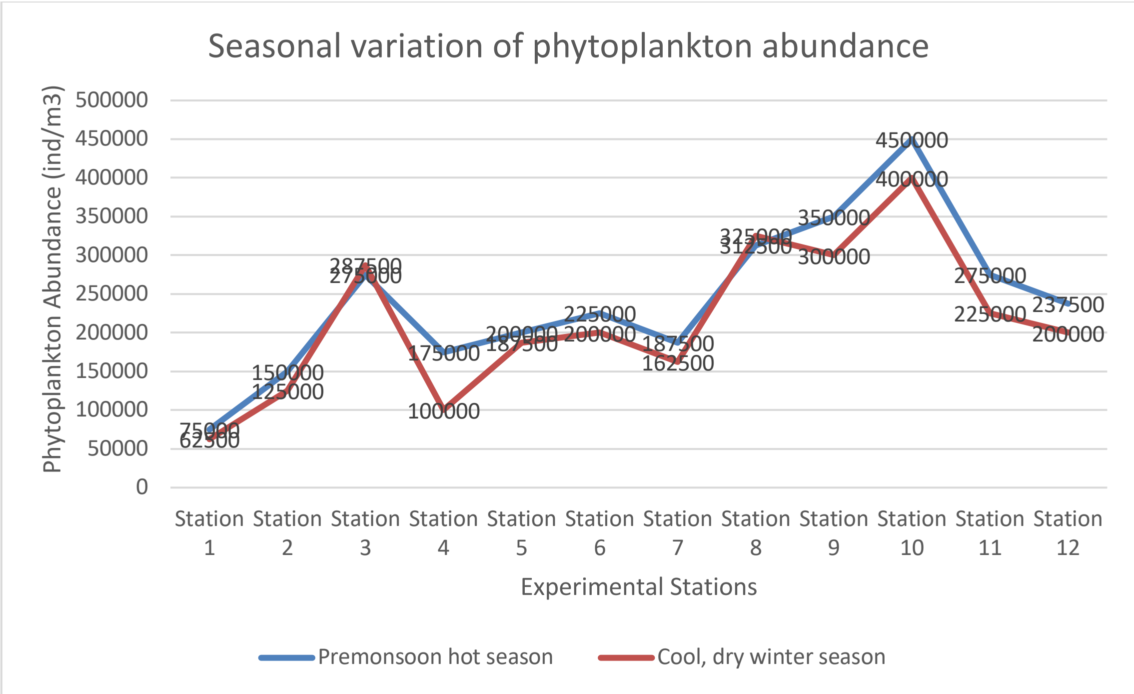


Fig: 6.15 Seasonal variation of the phytoplankton distribution in the coastal waters of St. Martin's Island

Table 6.2 Seasonal variation of the phytoplankton genera found in the coastal waters of St. Martin's Island

	Pre-monsoon hot season												Cool, dry winter season											
Genera	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Coscinodiscus	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Thalassiosira	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+
Rhizosolenia	-	-	+	+	+	+	+	+	+	+	-	-	-	-	+	-	+	-	-	+	+	+	-	-
Thalassionema	-	+	+	+	+	-	+	+	+	+	+	+	-	-	+	+	+	-	+	+	+	+	+	+
Chaetoceros.	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	-	-	+
Odontella	-	+	+	-	-	+	+	+	+	+	+	+	-	+	+	-	-	-	-	-	+	+	+	+
Gyrosigma	+	-	-	+	-	-	-	+	-	+	+	+	+	-	-	+	-	-	-	+	-	+	+	-
Detonula	-	-	+	-	-	-	+	+	+	+	-	-	-	-	+	-	-	-	+	+	+	+	-	-
Lauderia	-	-	-	-	+	+	-	+	-	+	+	-	-	-	+	-	-	+	-	+	-	+	+	-
Planktoniella	+	-	+	-	-	+	-	+	+	+	-	+	+	-	+	-	-	+	-	+	-	+	-	+
Bacteriastrum	-	-	-	-	+	-	-	-	-	+	-	-	-	-	-	-	+	-	+	+	-	+	-	-
Ceratium	-	-	+	-	-	+	-	-	+	+	+	-	-	+	+	-	-	+	-	-	+	+	+	-
Dinophysis	-	-	-	-	+	-	-	-	+	+	+	-	-	-	-	-	+	-	-	+	+	+	+	-
Gonyaulax	-	-	-	-	+	-	-	-	+	+	-	+	-	-	-	-	+	-	-	-	+	+	-	+

Pre-monsoon hot season (a) ***Cool dry winter season (b)***

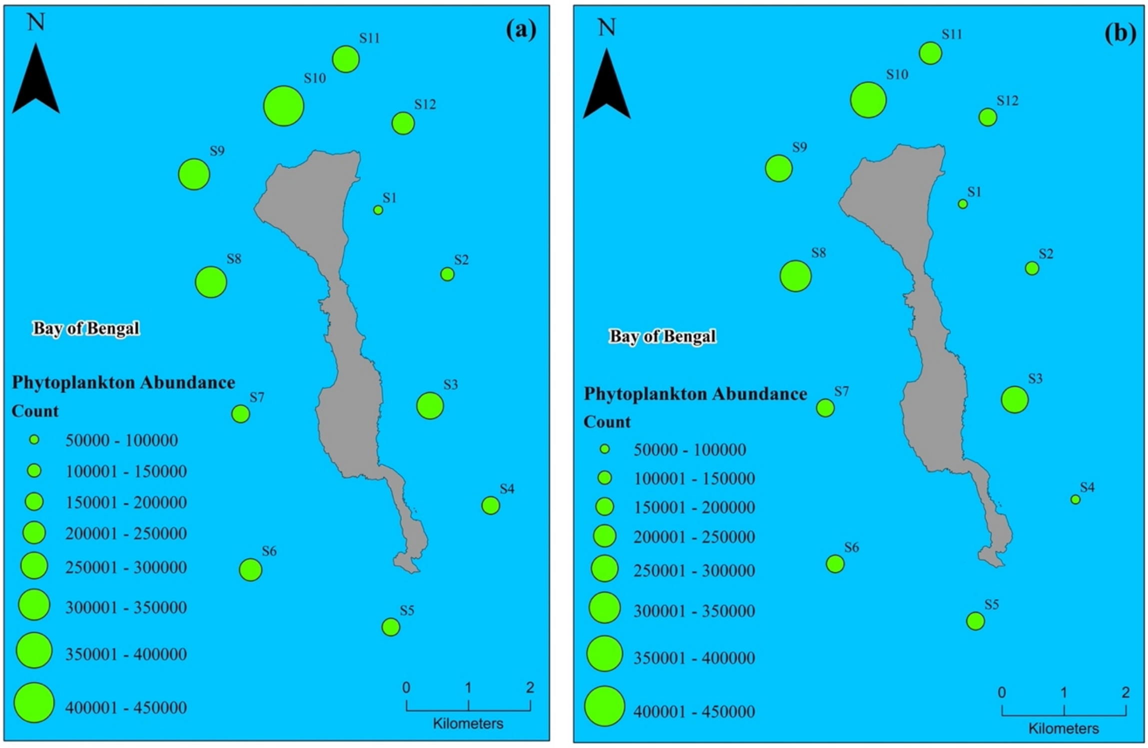


Figure 6.16 Seasonal variation of the phytoplankton abundance in the coastal waters of St. Martin's Island

After conducting the study during these two seasons, it was decided that the pre-monsoon hot season was better suited for cage culture in the coastal waters of St. Martin's Island. The pre-monsoon hot season had the higher phytoplankton abundance of the two seasons. The physicochemical parameters measured during this season were also well-suited for fish culture. So, detail study on the abundance, diversity and distribution of phytoplankton was conducted in that season.

In the detail study of the sample collected during the pre-monsoon hot season, a total of 55 species of phytoplankton were identified from the 12 stations adjacent to the coastal water of St. Martin's Island. A total of 49 diatom species and 6 dinoflagellate species were identified from the recorded phytoplankton population. Diatoms are the primary constituent of phytoplankton, with dinoflagellates comprising a secondary component.

Within the diatom group, the genera *Consinodiscus, Chaetoceros, Thalassiosira,* and *Thalassionema* are considered to be of utmost significance. Among dinoflagellates, 4 *Ceratium,* and one species from each of *Dinophysis* and *Gonyaulax*were found. The total density of phytoplankton varied from 75000-450,000 ind/m^3 and the highest was found at Station 11. *Cosinodiscus*is the most dominant genus in all the stations and the population of which ranged from 12,500-87,500 ind/m^3. Highest number of *Cosinodiscus* population was found at Station 10.

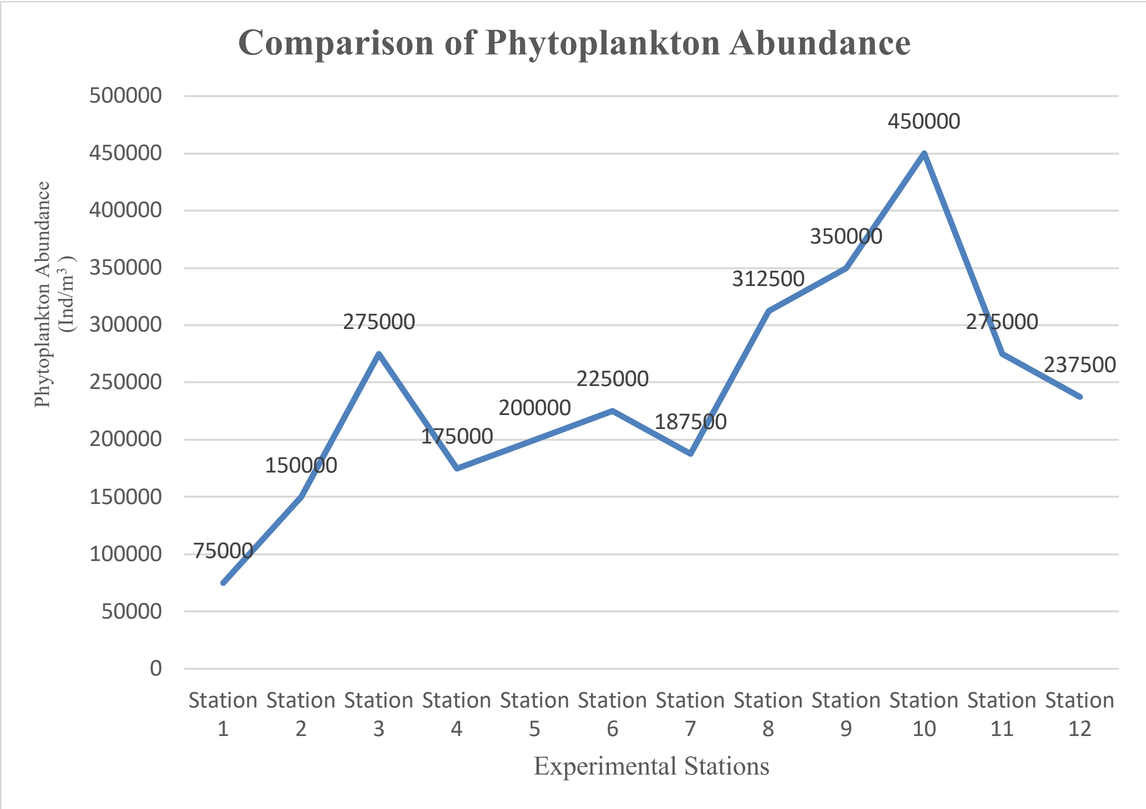


Figure 6.17 Comparison of Phytoplankton abundance in all sampling stations during pre-monsoon hot season

Table 6.3 Population density of Phytoplankton genera at different study stations during Pre-Monsoon hot season

Genera	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9	Station 10	Station 11	Station 12
Coscinodiscus	12500	37500	62500	37500	50000	37500	50000	87500	50000	75000	50000	25000
Thalassiosira	12500	25000	12500	25000	0	12500	25000	25000	25000	12500	12500	25000
Rhizosolenia	0	0	12500	12500	25000	25000	12500	25000	25000	37500	0	0
Thalassionema	0	12500	37500	25000	12500	0	12500	12500	37500	25000	25000	25000
Chaetoceros	12500	25000	12500	25000	12500	12500	12500	12500	12500	12500	37500	25000
Odontella	0	25000	25000	0	0	25000	25000	12500	25000	37500	25000	12500
Gyrosigma	0	0	0	25000	0	0	0	25000	0	25000	12500	37500
Detonula	0	0	12500	0	0	0	25000	12500	25000	25000	0	0
Lauderia	12500	0	0	0	25000	25000	0	25000	0	12500	12500	0
Planktoniella	0	0	25000	0	0	12500	0	25000	12500	25000	0	12500
Bacteriastrum	12500	0	0	0	12500	0	0	0	0	25000	0	0
Ceratium	0	0	12500	0	0	25000	0	0	25000	25000	25000	0
Dinophysis	0	0	0	0	25000	0	0	0	25000	12500	25000	0
Gonyaulax	0	0	0	0	12500	0	0	0	12500	25000	0	37500
Others	12500	25000	62500	25000	25000	50000	25000	50000	75000	75000	50000	37500

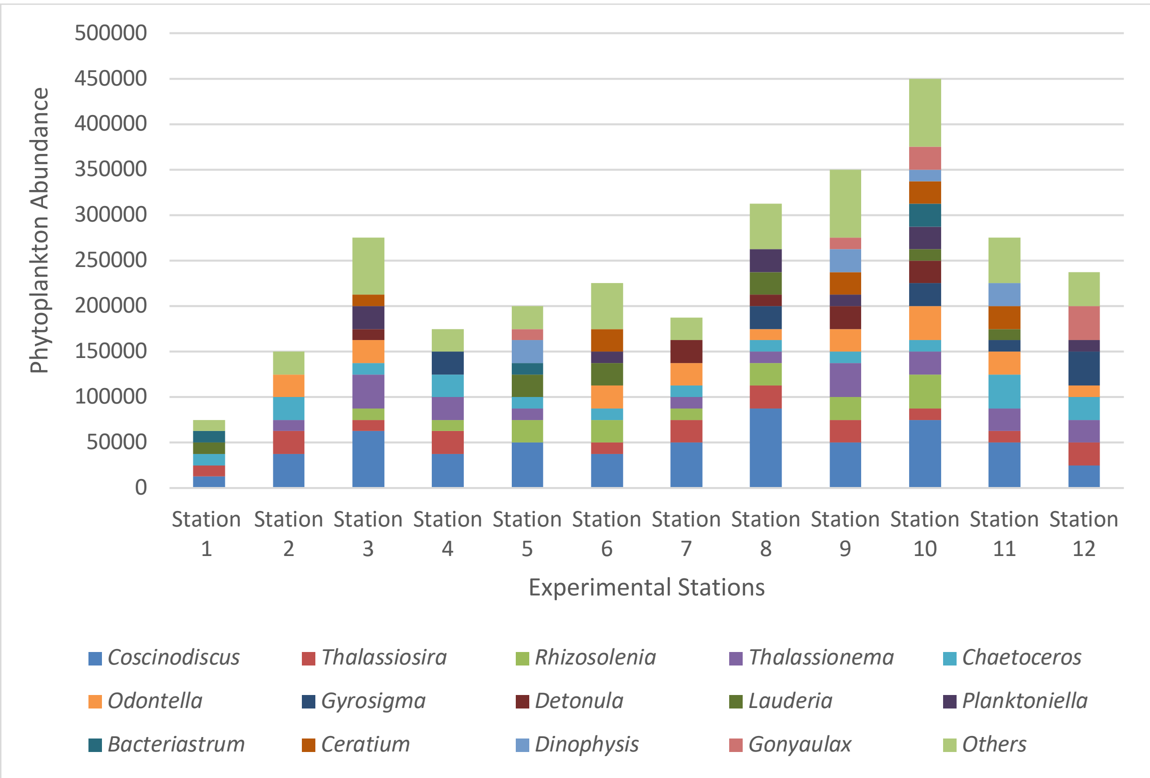


Figure 6.18 Comparison of different phytoplankton species abundance in all sampling stations during pre-monsoon hot season

<u>Species wise phytoplankton abundance in different stations during pre-monsoon hot season</u>

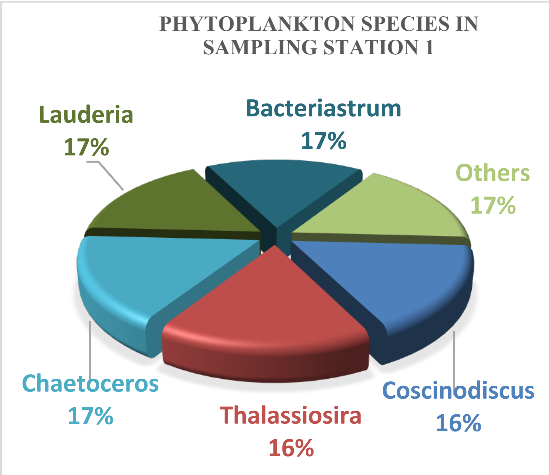


Figure 6.19 Phytoplankton species in sampling Station-1

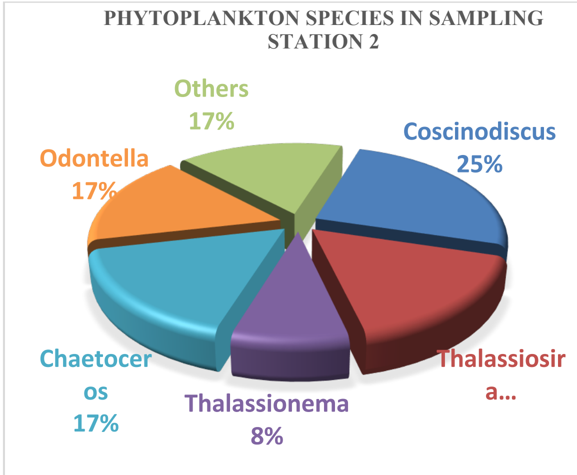


Figure 6.20 Phytoplankton species in sampling Station-2

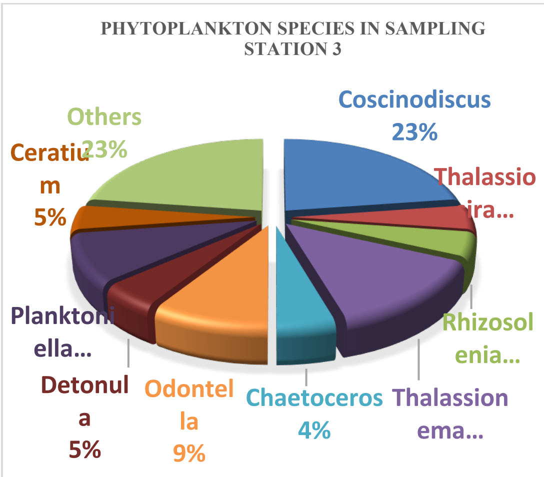


Figure 6.21 Phytoplankton species in sampling station-3

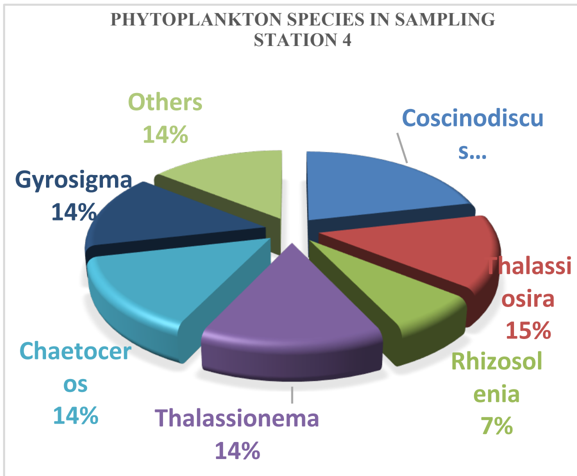


Figure 6.22 Phytoplankton species in sampling station-4

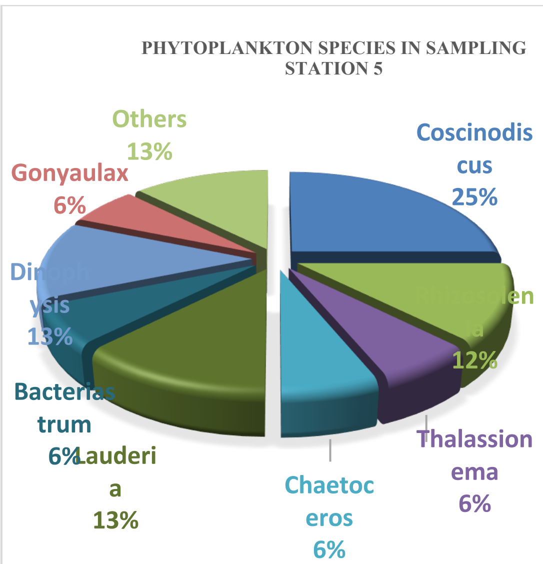


Figure 6.23 Phytoplankton species in sampling station-5

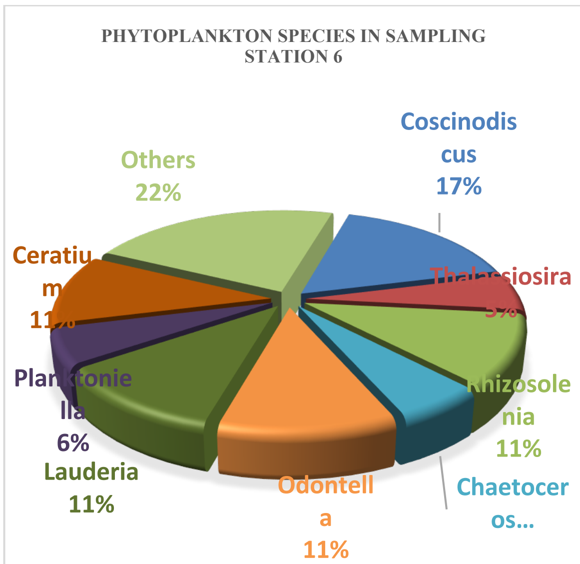


Figure 6.24 Phytoplankton species in sampling station-6

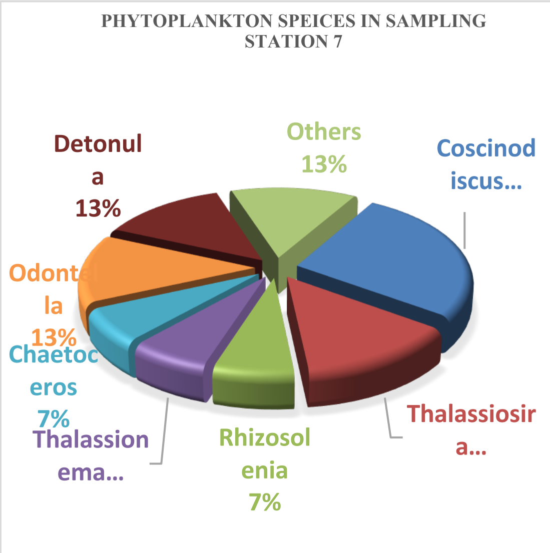


Figure 6.25 Phytoplankton species in sampling station-7

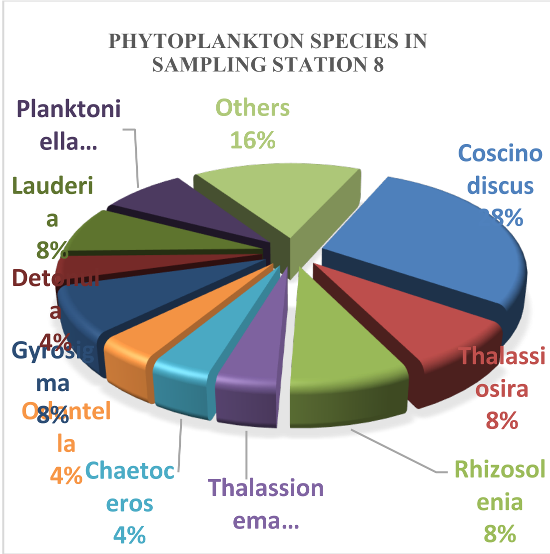


Figure 6.26 Phytoplankton species in sampling station-8

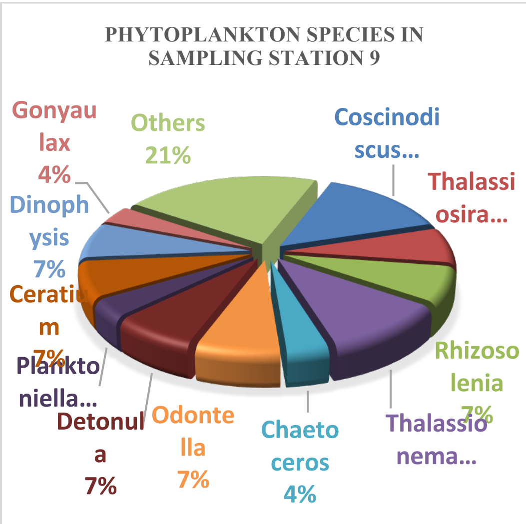


Figure 6.27 Phytoplankton species in sampling station-9

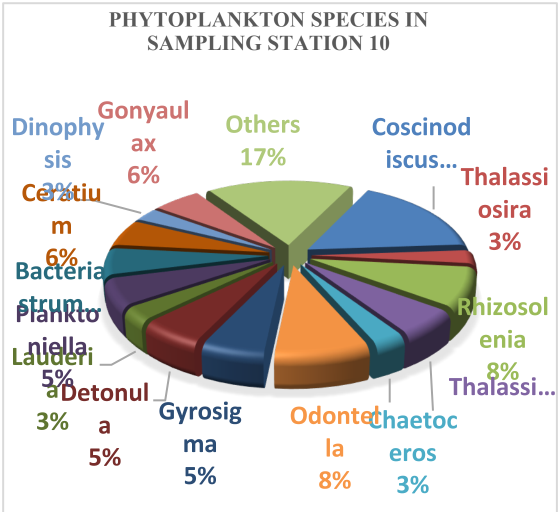


Figure 6.28 Phytoplankton species in sampling station-10

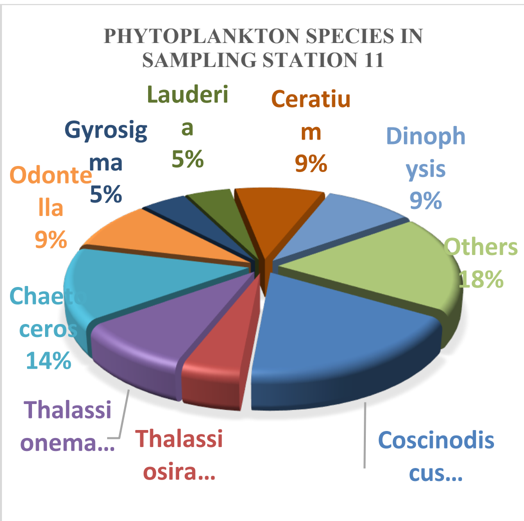


Fig 6.29 Phytoplankton species in sampling station-11

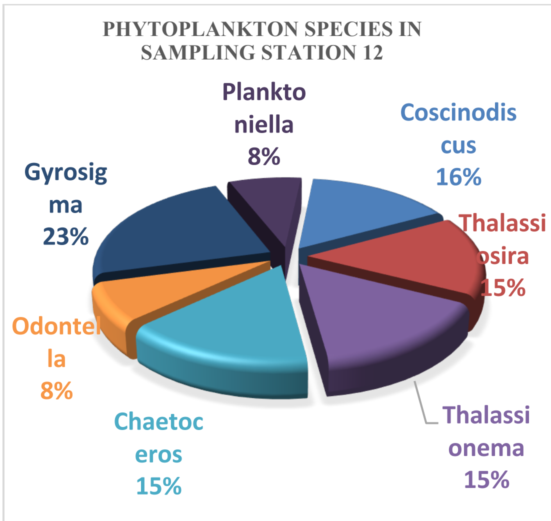


Fig 6.30 Phytoplankton species in sampling station-12

Table 6.4 Phytoplankton species recorded during pre-monsoon hot season at St. Martin's Island, Bangladesh.

DIATOMS		
Cosinodiscus radiates	*Th. longissima*	*Banquisia belgicae*
C. marginatus	*Thalassionema* sp.	*Eunotia* sp.
C. granii	*Chaetoceros neglectus*	*Thalasiosira oestrupii*
C. jonesianus	*Ch. coarctatus*	*Palmeria hardmaniana*
C centralis	*Ch. pseudocurvisetus*	*Thalasiothrix* sp.
Thalassiosira gravida	*Ch. constrictus*	*Noctiluca scintillans*
T. australis	*Ch. decipiens*	*Nitzschia acicularis*
T. pseudonana	*Ch. lorenzianus*	*Filodrillia delicatula*
T. punctigera	*Ch. tenuissimus*	*Ditylum brightwellii*
T. proschrinae	*Ch. danicus*	*Ditylum cornutum*
Rhizosolenia formosa	*Odontella sinensis*	*Ditylum* sp.
R. castracanei	*O. mobiliensis*	
R. terperei	*Odontella* sp.	DINOFLAGELLATES
R. imbricata	*Gyrosigma* sp.	*Ceratium furca*
R. robusta	*Detonnula pumila*	*Cer. tripos*
Rhizosolenia. sp.	*Lauderia annulata*	*Cer. macroceros*
Thalassionema frauenfeldii	*Planktoniella* sp.	*Cer. trichoceros*
Th. bacillare	*Lauderia* sp.	*Dinophysis tripos*
Th. nitzschioides	*Bacteriastrum furcata*	*Gonyaulax scrippsae*

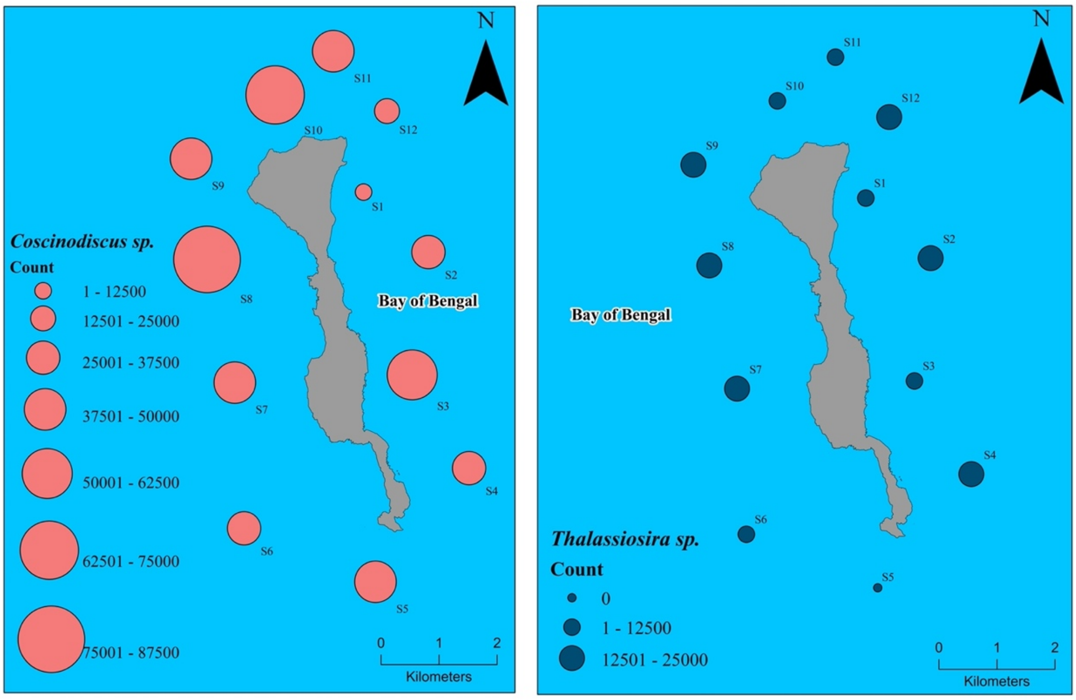


***Figure 6.31 Coscinodiscus sp. and Thalassiosira sp.* distribution around St. Martin's Island**

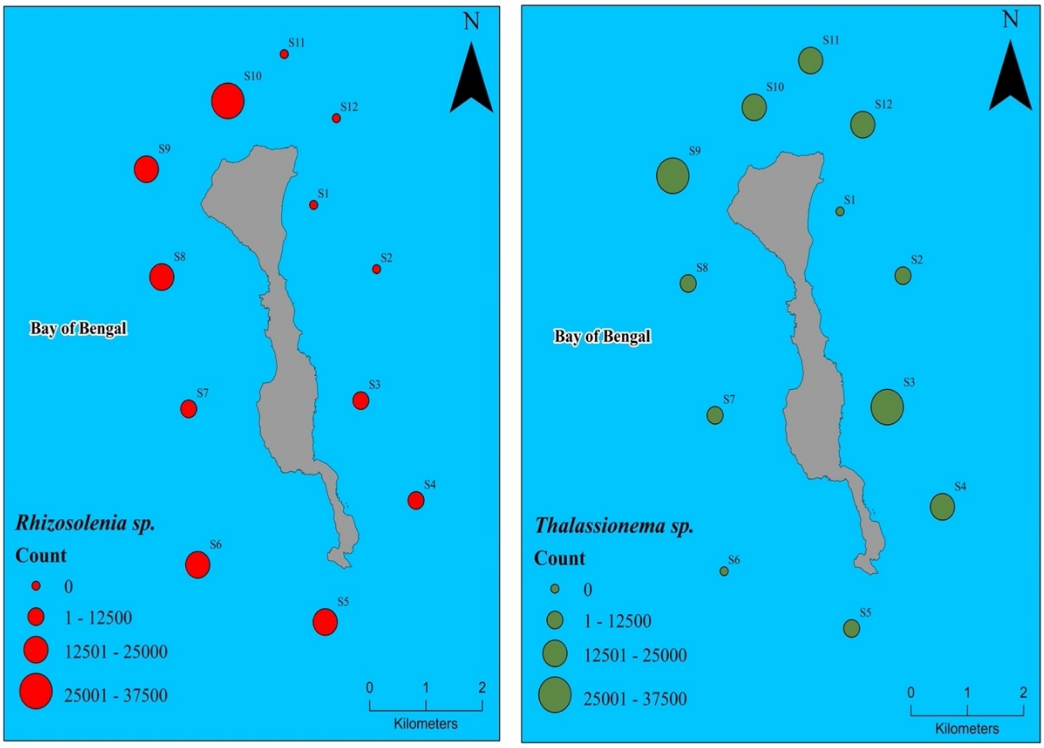


Figure 6.32 ***Rhizosolenia sp.*** **and** ***Thalassionema sp.*** **distribution around St. Martin's Island**

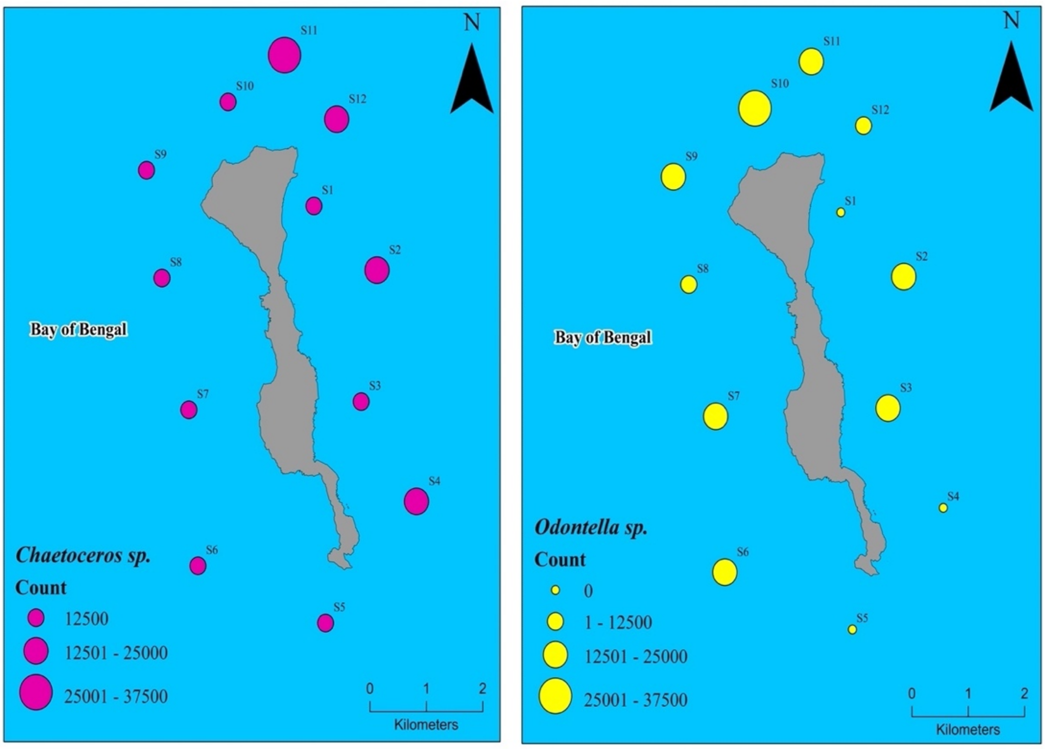


Figure 6.33 ***Chaetoceros sp.*** **and** ***Odontella sp.*** **distribution around St. Martin's Island**

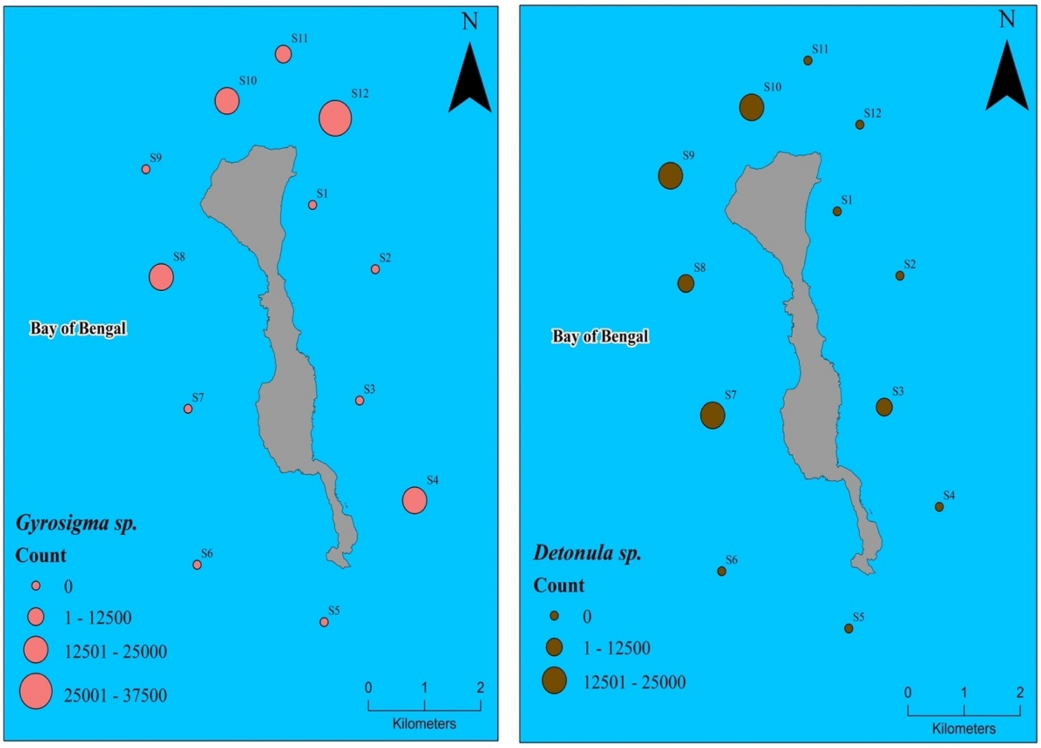


Figure 6.34 ***Gyrosigma sp.*** **and** ***Detonula sp.*** **distribution around St. Martin's Island**

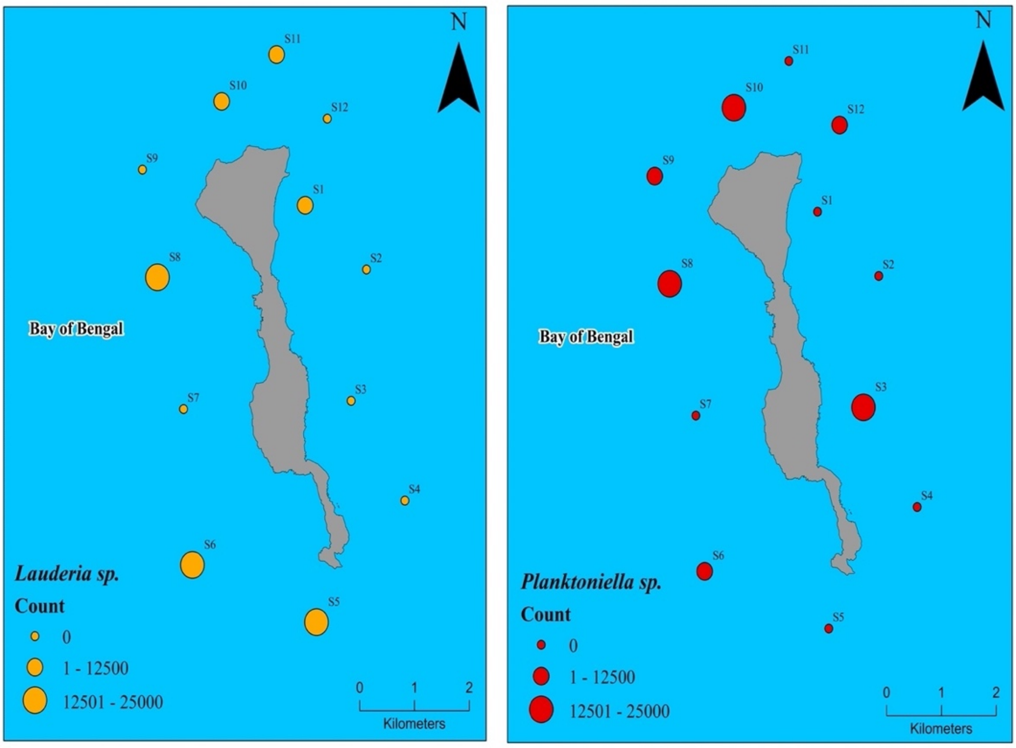


Figure 6.35 ***Lauderia sp.*** **and** ***Planktoniella sp.*** **distribution around St. Martin's Island**

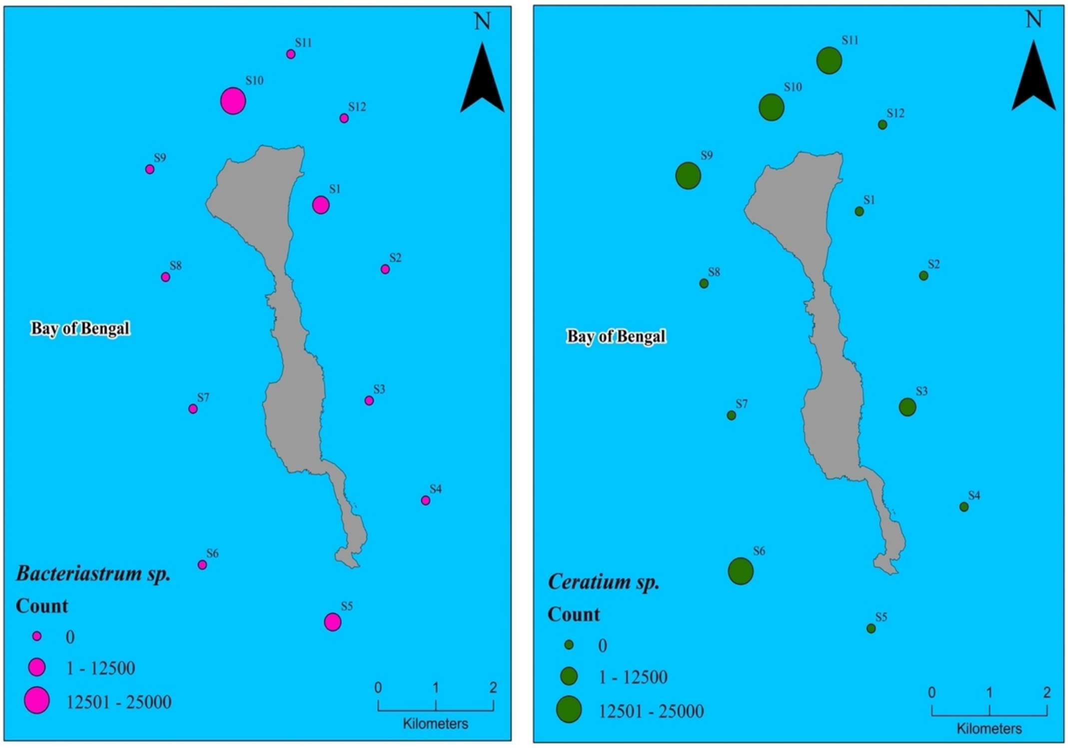


Figure 6.36 ***Bacteriastrum sp.*** **and** ***Ceratium sp.*** **distribution around St. Martin's Island**

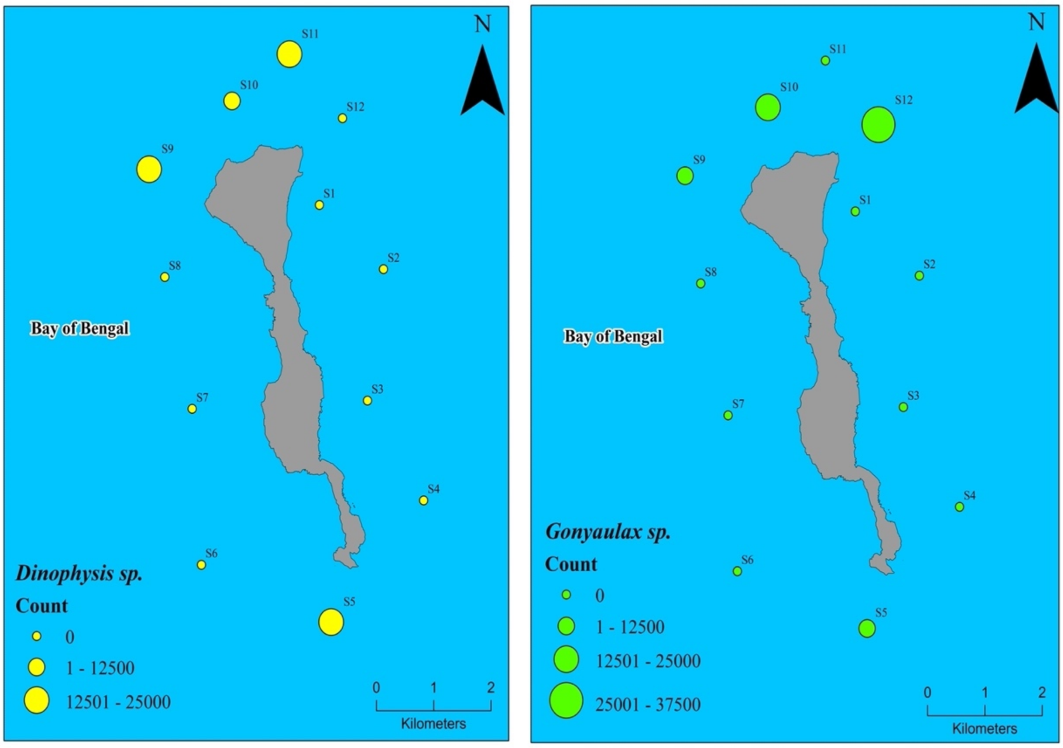


Figure 6.37 ***Dinophysis sp.*** **and** ***Gonyaulax sp.*** **distribution around St. Martin's Island**

6.2.1.a Phytoplankton Richness and Shannon-Wiener Index

The analysis of diversity and species richness revealed that station 1 & 2 exhibited the lowest species richness value of 1.52, whereas station 10 displayed the highest species richness value of 4.93. In contrast, Station 2 exhibited the lowest diversity score of 1.56, while Station 10 displayed the highest diversity value of 2.50. The observed data suggests that the phytoplankton population at station 10 exhibits a larger carrying capacity in comparison to the other stations under investigation.

Table 6.5 Phytoplankton Richness and Shannon-wiener index during Pre-Monsoon Hot Season

Sampling Stations	Number of Genera	Species Richness	Shannon-Wiener Index
Station 1	5	1.52	1.61
Station 2	5	1.52	1.56
Station 3	9	3.03	2.00
Station 4	6	1.89	1.75
Station 5	8	2.65	1.95
Station 6	8	2.65	2.01
Station 7	7	2.27	1.82
Station 8	10	3.41	2.07
Station 9	11	3.79	2.31
Station 10	14	4.93	2.50
Station 11	9	3.03	2.09
Station 12	8	2.65	2.01

6.2.2 Zooplankton's Abundance and Distribution in the Coastal waters adjacent to St. Martin's Island

The locations were sampled for physicochemical properties before the monsoons, during the monsoons, and in the dry, cold winter. The zooplankton plankton sample was only taken during the hot pre-monsoon season and the cool, dry winter season due to the restriction of St. Martin's going vessel during the rainy monsoon season and for the difficulties of mariculture during that season. To ascertain the appropriate season and location for cultivating zooplankton feeder fish in cages within the coastal waters of St. Martin's Island, it is imperative to get comprehensive data pertaining to the year-round abundance, variety, and distribution of zooplankton.

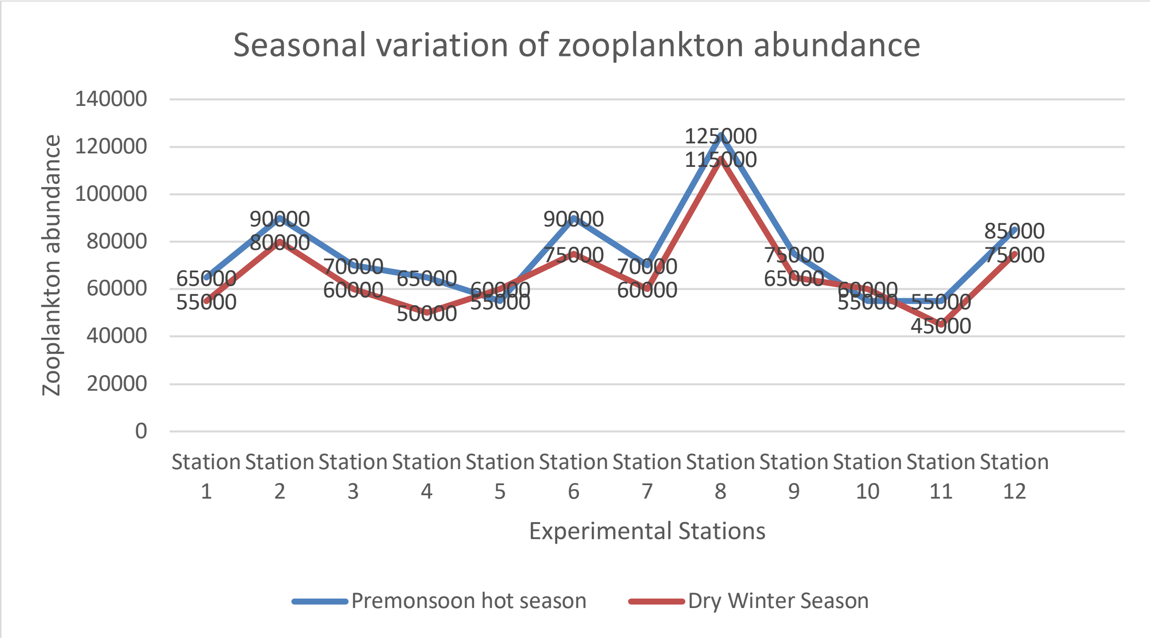


Figure 6.38 Seasonal variation of the zooplankton abundance in the coastal waters of St. Martin's Island

Table 6.7 Seasonal variation of the zooplankton genera found in the coastal waters of St. Martin's Island

	Pre-monsoon hot season												Cool, dry winter season											
Genera	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Balanus sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Canthocalanus sp.	-	+	-	-	-	+	-	+	+	-	-	-	-	+	-	-	+	+	-	+	+	-	-	-
Clausocalanus sp.	+	-	+	-	-	-	+	-	-	-	-	+	-	-	+	-	-	-	+	-	-	-	+	+
Euterpina sp.	-	-	-	+	+	-	-	+	-	+	-	+	-	-	-	+	-	-	-	-	-	+	-	-
Hyperia sp.	-	+	+	-	-	+	-	+	-	-	-	+	-	+	+	-	+	+	-	+	-	+	-	+
Labidocera sp.	+	+	-	+	+	-	+	+	+	-	+	-	+	+	-	+	+	-	+	-	+	-	-	-
Microsetella sp.	+	+	-	+	-	+	+	+	+	+	-	+	+	+	-	-	-	+	-	+	+	+	-	+
Oithona sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+
Oncaea sp.	+	+	-	-	-	+	-	+	-	+	+	-	+	+	-	-	-	-	-	+	-	+	-	-
Tintinnopsis sp.	-	-	+	+	+	+	-	-	+	-	-	-	-	-	+	+	+	+	-	-	+	-	-	-

Pre-monsoon hot season (a) ***Cool dry winter season (b)***

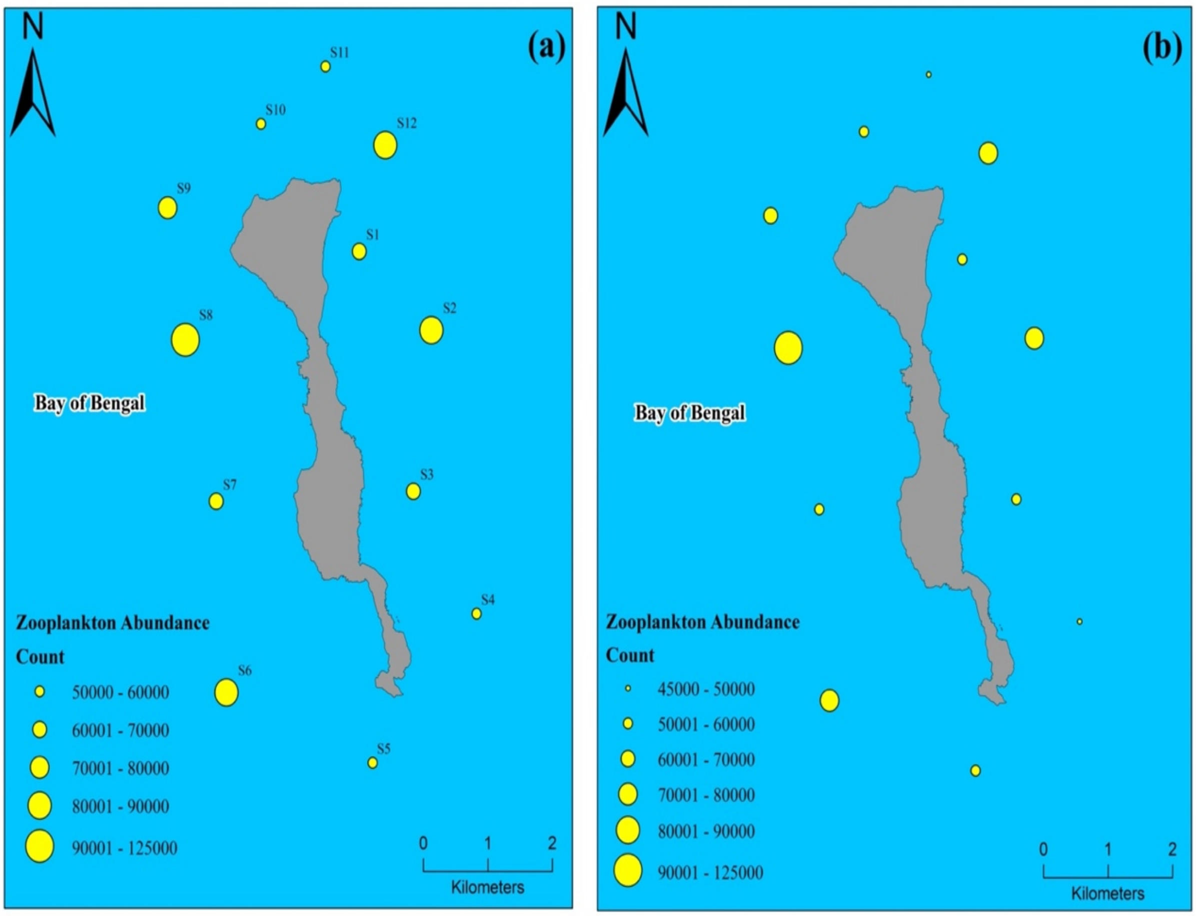


Figure 6.39 Seasonal variation of the abundance of zooplankton distribution in the coastal waters of St. Martin's Island

Possibility of cage culture of zooplankton feeder fish in the coastal waters of St. Martin's Island was studied throughout both of these seasons, and it was determined that the pre-monsoon hot season would be optimal for the purpose. Zooplankton feeder fish are an essential component of marine ecosystems because of the important role they play in the movement of energy up the ocean food chain from primary producers (such as phytoplankton) to higher trophic levels.

These fish get the majority of their nutrition from zooplankton, which are drifting invertebrates of a microscopic size and include copepods, krill, small jellyfish, and other organisms of a similar size. The consumption of zooplankton is necessary for the survival of a great number of fish species, particularly those that are found lower on the food chain.

According to the findings of the study, the abundance of zooplankton was at its peak right before the onset of the monsoons, and it stayed high all the way through the season. Measured physicochemical parameters this season also showed favorable conditions for fish farming. Hence, extensive research of zooplankton abundance, variety, and distribution was carried out during that time period. Based on the findings of the study, it is possible to draw the conclusion that station 8 provides the conditions that are the most suitable for the application of cage culture to the cultivation of a zooplankton feeder fish.

The significance of these fish that feed on zooplankton extends beyond their role in maintaining their own populations, as they also play a crucial role in the flow of energy throughout the food chain. Predatory organisms, such as larger fish, seabirds, and marine mammals, depend on these little fish as a fundamental source of sustenance. The significance of zooplankton and their role as a food source for fish in sustaining marine ecosystems is underscored by the intricate interconnections within the oceanic web of life.

During the comprehensive examination of the samples obtained during the pre-monsoon, a total of 34 distinct species of zooplankton were successfully identified. These samples were gathered from 12 distinct sampling sites located in the coastal waters adjacent to St. Martin's Island. The majority of the observed species consisted of copepods. Additionally, the community exhibited the presence of polychaete and rotifer organisms.

The genera of *Balanus, Oithona, Canthocalanus, Euterina,* and *Microstella,* among others, encompassed the most significant species. The abundance of zooplankton ranged from 55,000 to 125,000 individuals per cubic meter, with the greatest concentration seen at station 8. *Oithona and Microsetella* had the highest levels of dominance across all sampling points. This study exhibits resemblances with the subsequent studies described in discussion sections.

Table 6.6 Population density of different zooplankton genera at the study stations during pre-monsoon hot season

Genera	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9	Station 10	Station 11	Station 12
Balanus sp.	5000	10000	5000	5000	5000	5000	5000	15000	5000	5000	10000	10000
Canthocalanus sp.	0	5000	0	0	0	10000	0	5000	5000	0	0	0
Clausocalanus sp.	5000	0	5000	0	0	0	5000	0	0	0	0	5000
Euterpina sp.	0	0	0	5000	5000	0	0	10000	0	5000	0	5000
Hyperia sp.	0	5000	10000	0	0	5000	0	5000	0	0	0	10000
Labidocera sp.	5000	10000	0	5000	5000	0	10000	10000	10000	0	10000	0
Microsetella sp.	10000	10000	0	15000	0	10000	15000	20000	5000	10000	0	10000
Oithona sp.	10000	5000	10000	10000	10000	5000	10000	10000	5000	5000	5000	15000
Oncaea sp.	10000	5000	0	0	0	10000	0	10000	0	10000	10000	0
Tintinnopsis sp.		0	10000	5000	10000	5000	0	0	10000	0	0	0

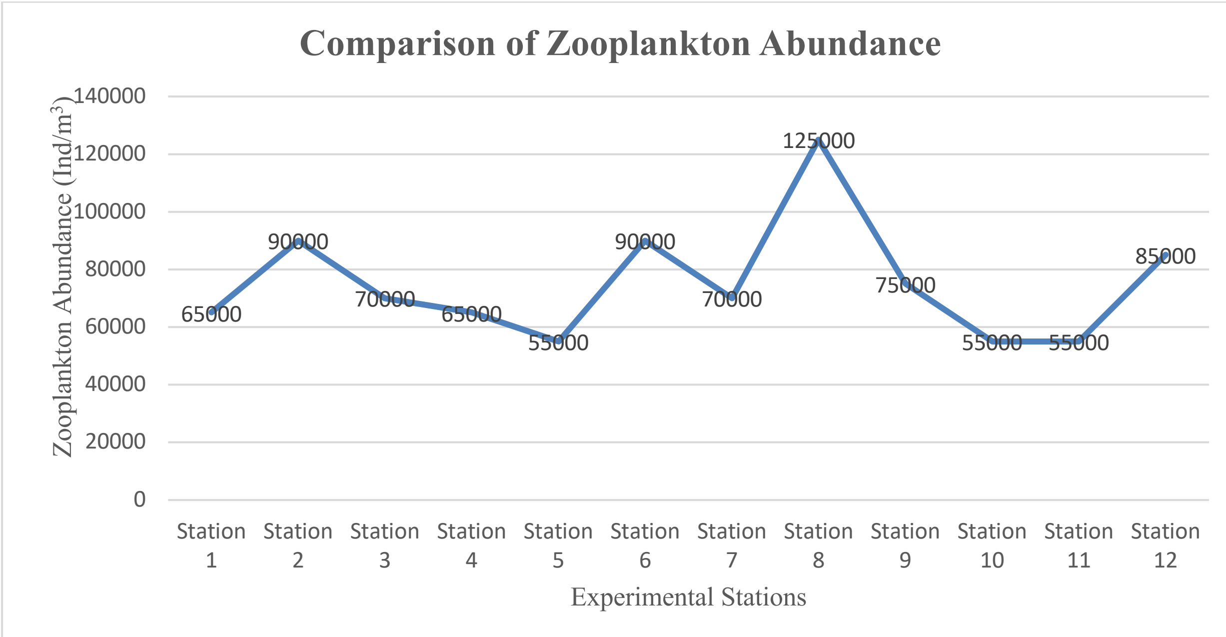


Figure 6.40 Comparison of zooplankton abundance in all sampling stations during pre-monsoon hot season

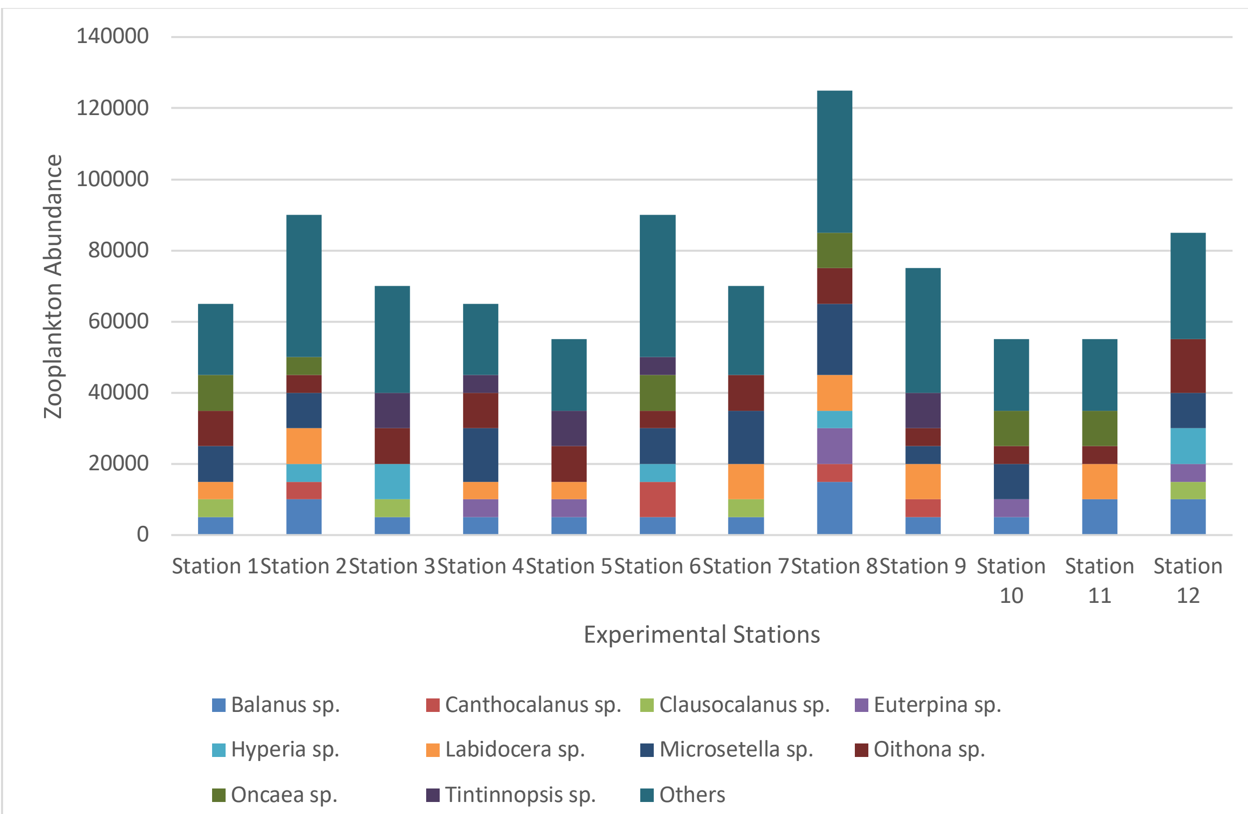


Figure 6.41 Comparison of different zooplankton species in all sampling stations during pre-monsoon hot season

<u>Species wise Zooplankton abundance in different stations during pre-monsoon hot season</u>

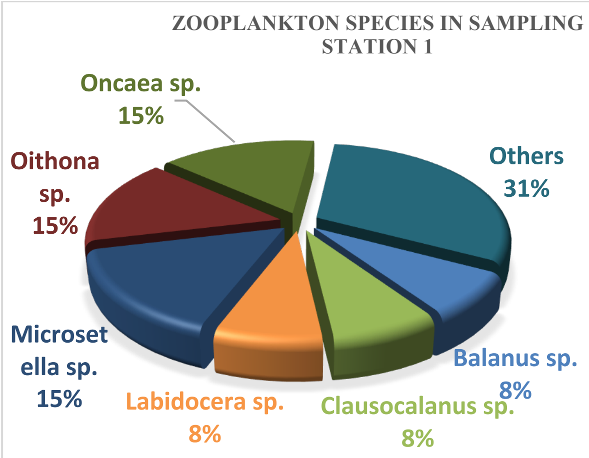


Figure 6.42 Zooplankton species in sampling station-1

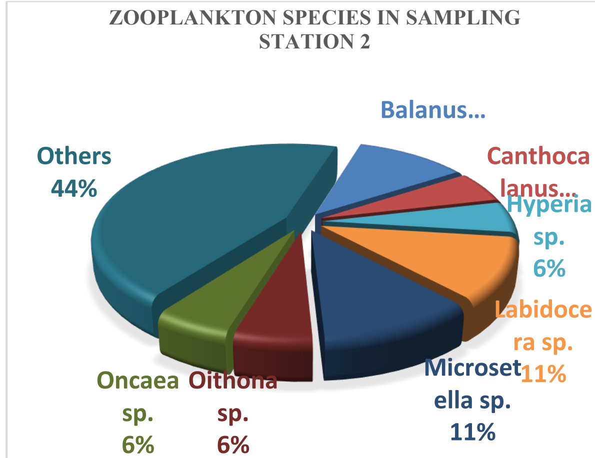


Figure 6.43 Zooplankton species in sampling station-2

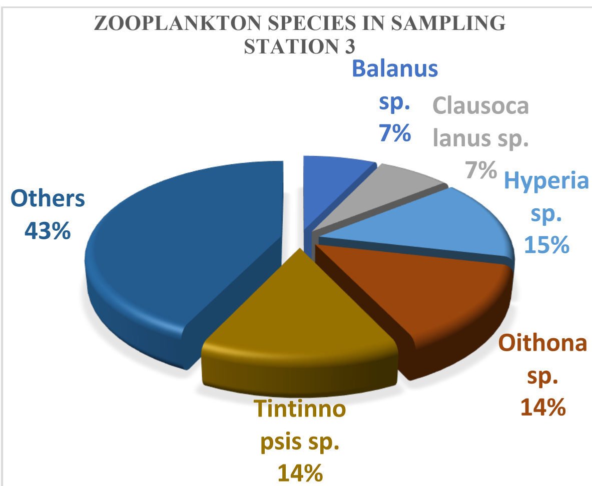


Figure 6.44 Zooplankton species in sampling station-3

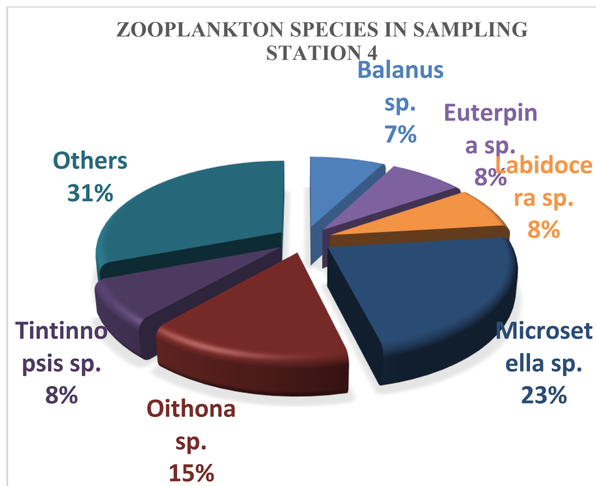


Figure 6.45 Zooplankton species in sampling station-4

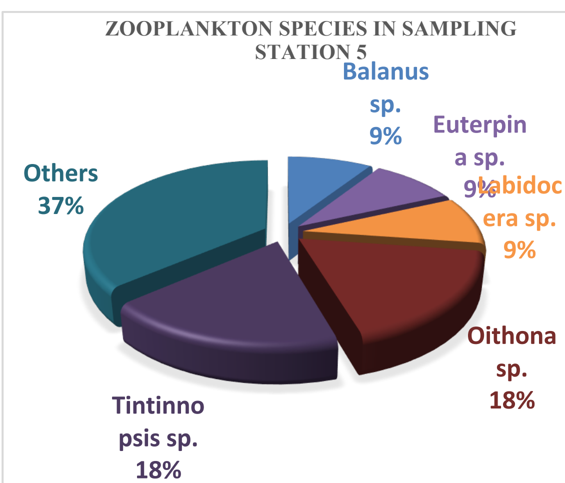


Figure 6.46 Zooplankton species in sampling station-5

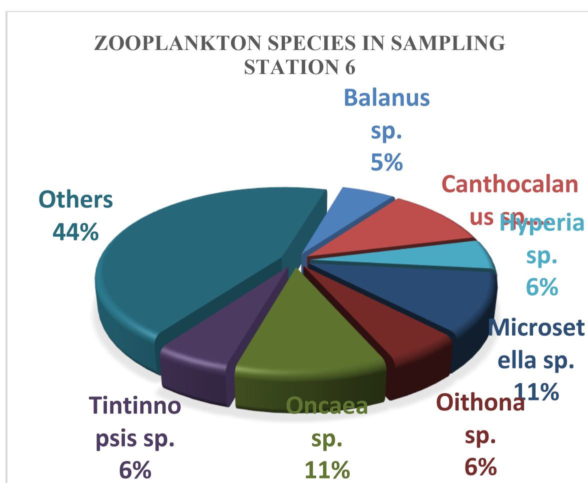


Figure 6.47 Zooplankton species in sampling station-6

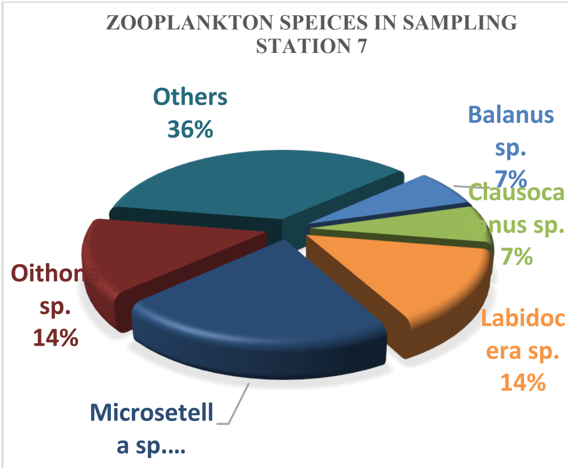


Figure 6.48 Zooplankton species in sampling station-7

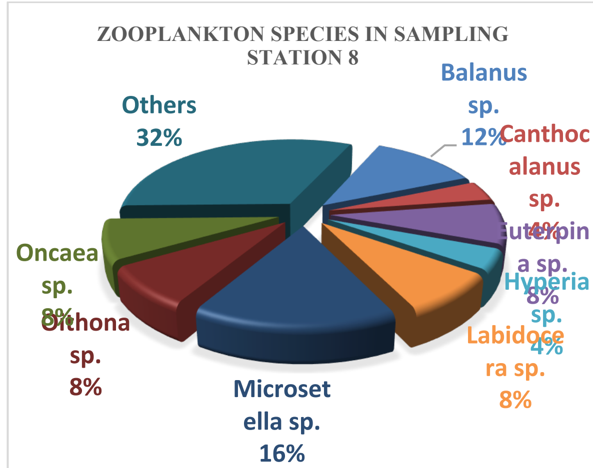


Figure 6.49 Zooplankton species in sampling station-8

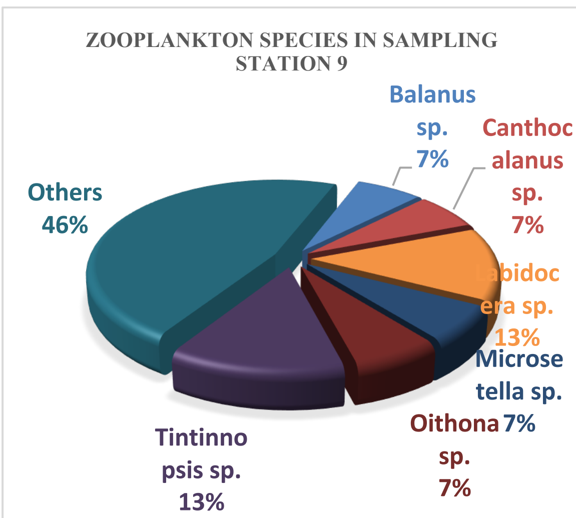


Figure 6.50 Zooplankton species in sampling station-9

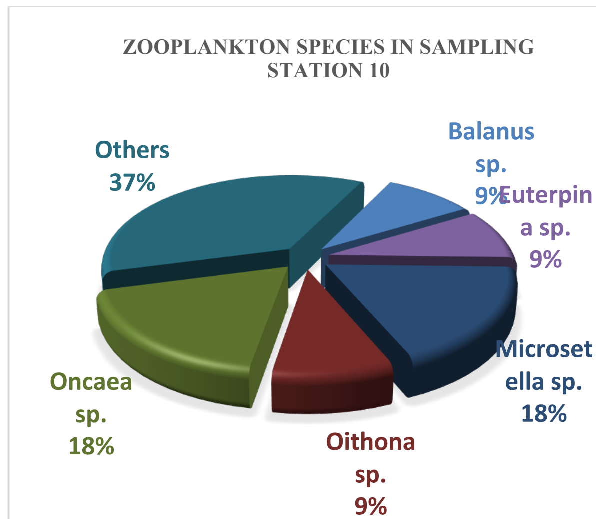


Figure 6.51 Zooplankton species in sampling station-10

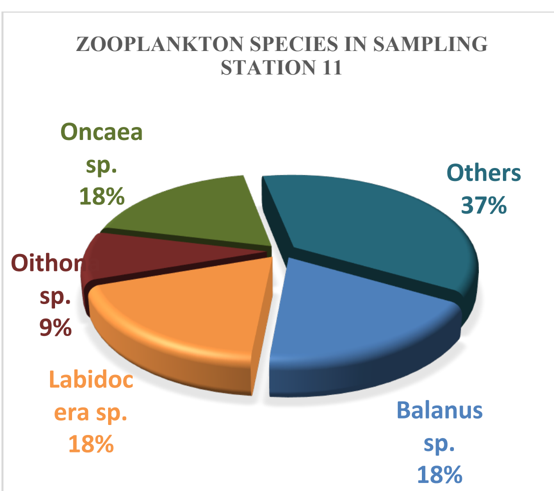


Figure 6.52 Zooplankton species in sampling station-11

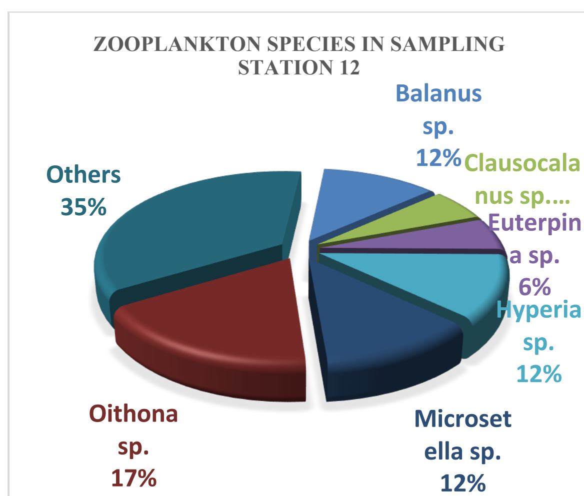


Figure 6.53 Zooplankton species in sampling station-12

Table 6.7 Zooplankton species recorded in the adjacent regions of St. Martin's Island during pre-monsoon hot season

Acartia pacifica	*Evadne* sp.	*Oithona similis*
Balanus glandula	*Hyperia galba*	*Oithona* sp.
Canthacalanus pauper	*Labidocera bengalensis*	*Oncaea minuta*
Clausocalanus arcuicornis	*Labidocera* sp.	*Oncaea* sp.
Clausocalanus sp.	*Metis jousseaumei*	*Podon* sp.
Clytemnestra scutellata	*M. rosea*	*Pseudonereis* sp.
Corycaeus agilis	*Metridia lucens*	*Subeucalanus flemingeri*
Ditrichocorycaeus andrewsi	*Microsetella norvegica*	*T. longicornis*
Euphausia sp.	*O. brevicornis*	*Temora dicaudata*
Euterpina acutifrons	*O. nana*	*Thysanoessa raschii*
Euterpina sp.	*Octolasmis* sp.	*Tintinnopsis* sp.
Eutintinnus sp.		

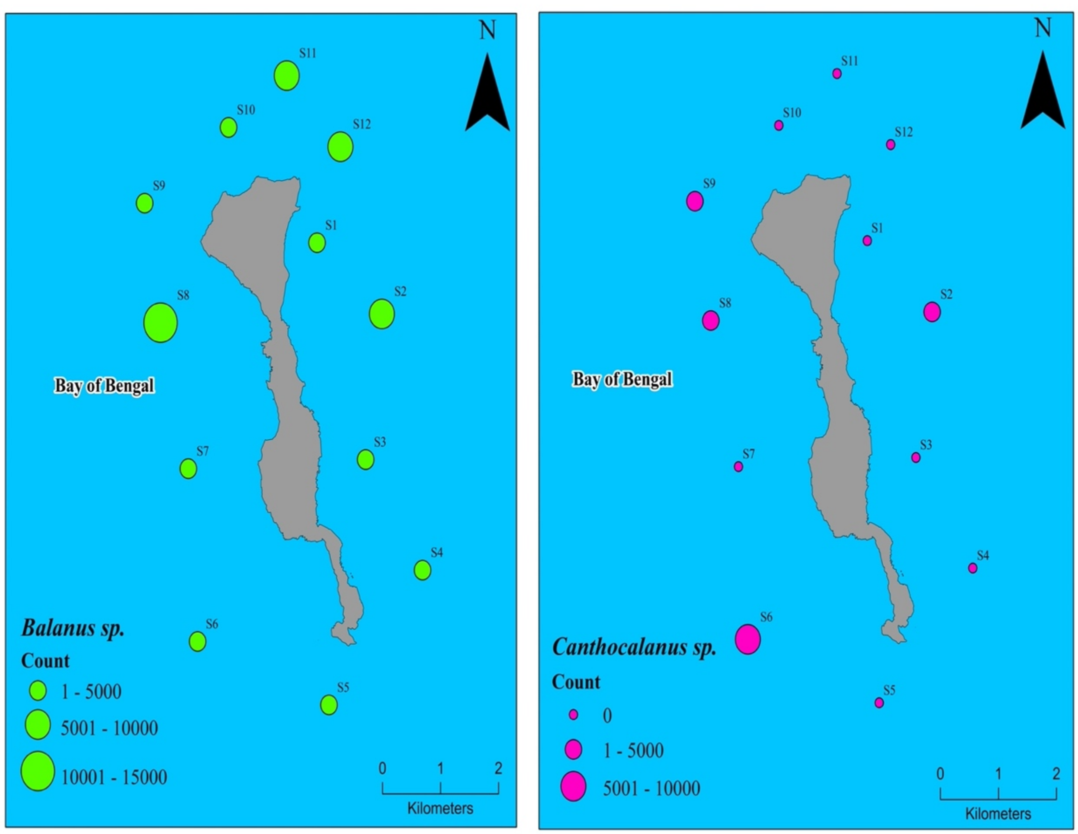


Figure 6.54 *Balanus sp.* and *Canthocalanus sp.* distribution around St. Martin's Island

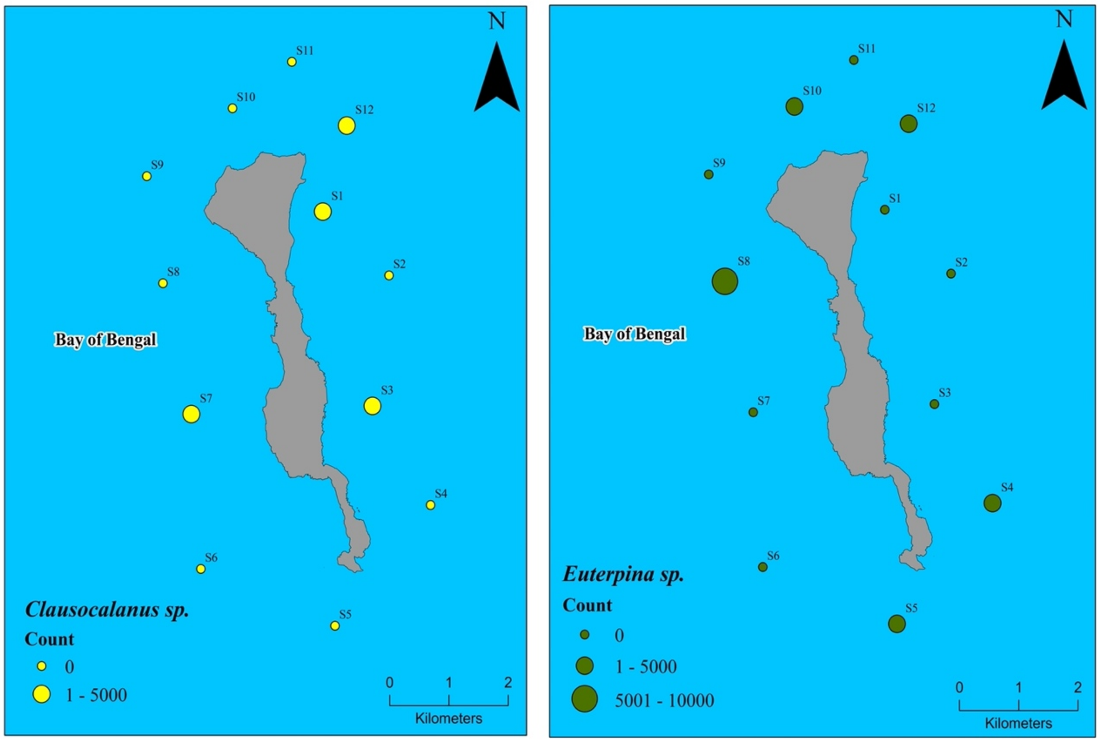


Figure 6.55 ***Clausocalanus sp. and Euterpina sp.*** **distribution around St. Martin's Island**

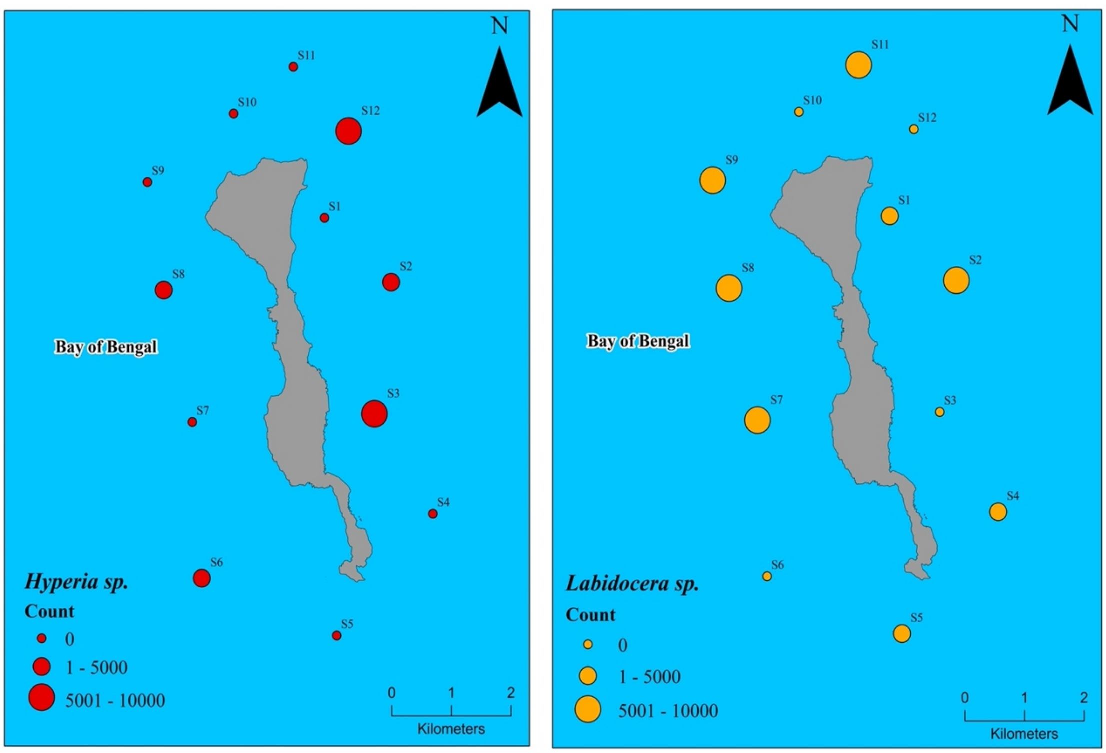
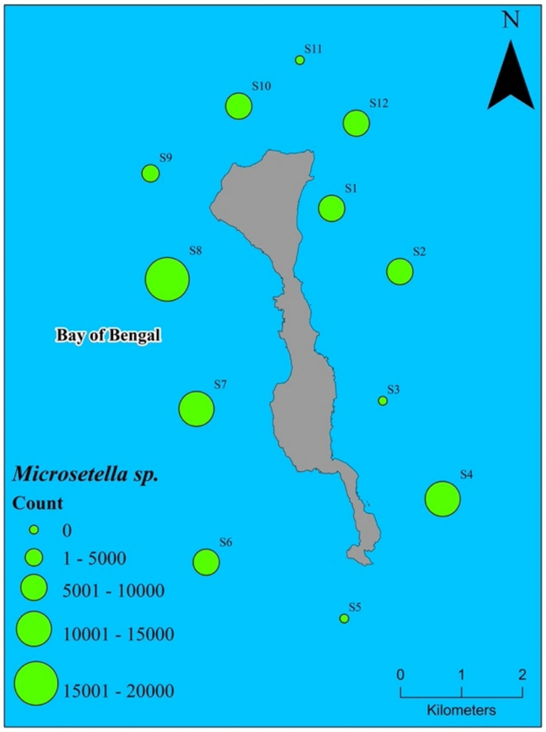


Figure 6.56 ***Hyperia sp.*** **and** ***Labidocera sp.*** **distribution around St. Martin's Island**



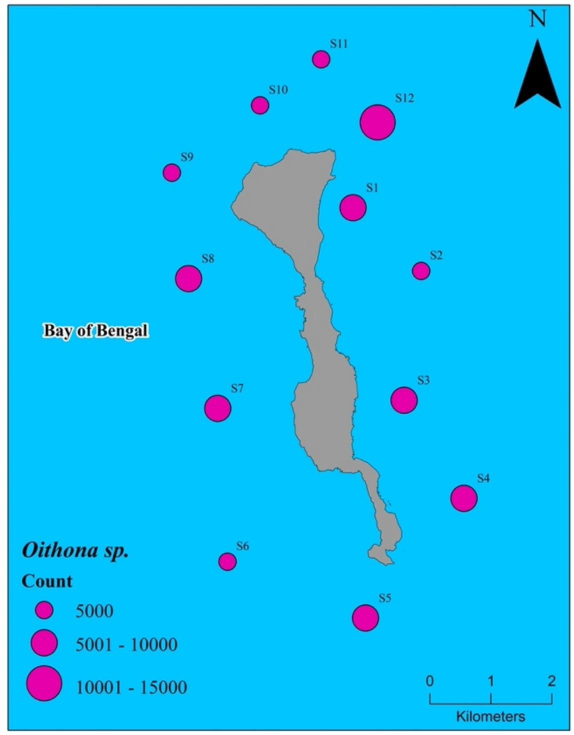
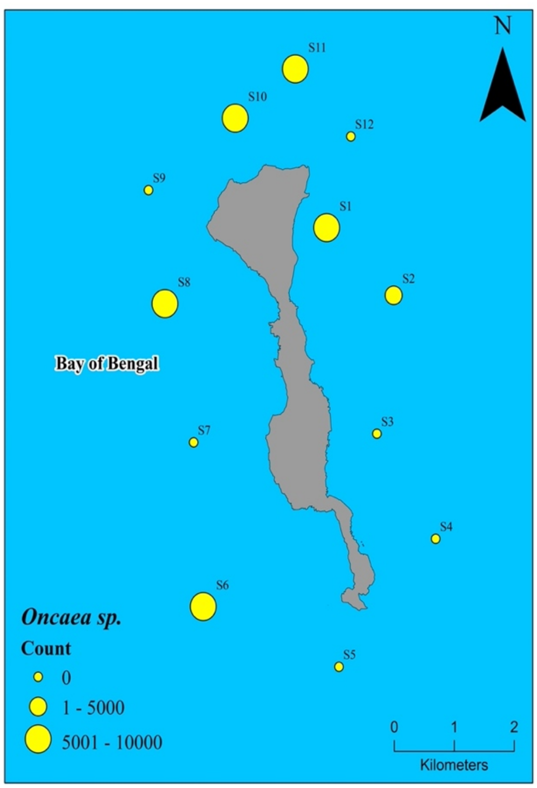


Figure 6.57 ***Microsetella sp.*** **and** ***Oithona sp.*** **distribution around St. Martin's Island**



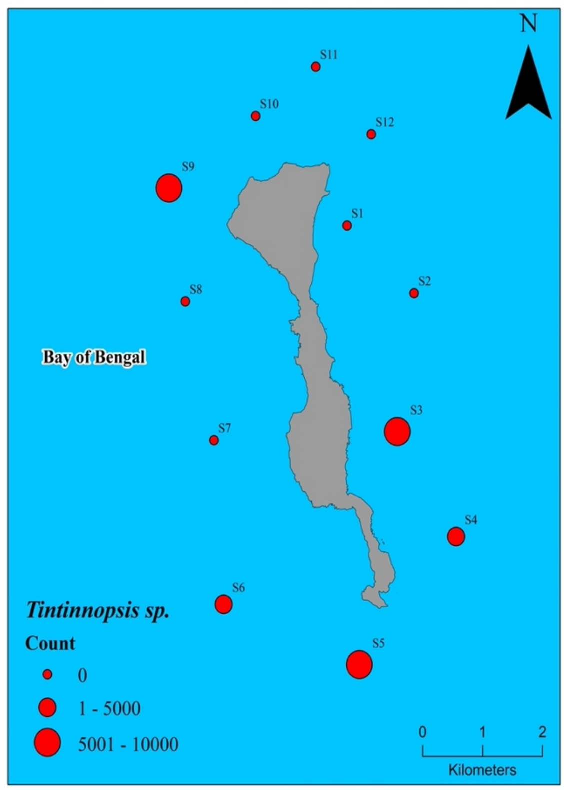


Figure 6.58 ***Oncaea sp.*** **and** ***Tintinnopsis sp.*** **distribution around St. Martin's Island**

The provided figures depict area plots representing the abundance of zooplankton at a generic level across several stations of interest. These plots enable the clear visualization of the highest and lowest levels of zooplankton abundance. The stations exhibited varying levels of population abundance, with *Microstella* and *Oithona* being the most prevalent species observed.

6.2.2.a Zooplankton Richness and Shannon-Wiener Index

Table 6.8 depicts the results of the Shannon-Wiener Index together with the number of genera recorded at each station, population density, and the Shannon-Wiener Index. Based on the findings, it is apparent that station 11 exhibited the lowest diversity index (1.35), while station 8 demonstrated the highest index (1.93).

Table 6.8 Shannon-Wiener Index and Species Richness at the sampling stations

Sampling Stations	Number of Genera	Species Richness	Shannon-Wiener Index
Station 1	6	2.17	1.74
Station 2	7	2.61	1.89
Station 3	5	1.74	1.56
Station 4	6	2.17	1.68
Station 5	5	1.74	1.55
Station 6	7	2.61	1.89
Station 7	5	1.74	1.52
Station 8	8	3.04	1.93
Station 9	6	2.17	1.73
Station 10	5	1.74	1.55
Station 11	4	1.30	1.35
Station 12	6	2.17	1.72

Furthermore, based on the data presented in table 6.8, it can be determined that station 8 exhibited the highest level of species richness, with a value of 3.04. In contrast, stations 11 had the lowest level of species richness, with a value of 1.30.

6.3 Seasonal Variation and Spatial Distribution of Nutrients in the Coastal waters of St. Martin's Island

Observations of seasonal variation were made in the coastal waters adjacent to St. Martin's Island in the Bay of Bengal to examine the influence of physical processes and the distribution pattern of nutrients (Nitrate, Nitrite, Silicate, Ammonia, Phosphate) in the oceanic water. In this regard, two seasons, Cool dry winter season, 2020 and Pre-monsoon hot season 2021, were taken into account from 12 distinct sampling locations at the periphery of the island. The study observed some distinct variation between two seasons whereas the concentration of the nutrients was higher in the Cool dry winter season in comparison to the Pre-monsoon hot season. Integration of principle component analysis (PCA) and Pearson's Correlation revealed that fresh water input from the adjacent rivers, upwelling of deep water, and, in a few cases, minor anthropogenic sources are vital. The spatial variation of nutrients delineated that north-western and south-eastern region of the island is higher in nutrient concentration. pH, DO, Temperature, Salinity and TDS were also measured during those seasons to find out the correlations between the physicochemical parameters and the nutrients. This investigation may assist to comprehend the present marine condition of Saint Martin's Island.

6.3.1 Seasonal variation of Physicochemical Parameters and Nutrients in the Coastal waters of Saint Martin's Island

Physicochemical characteristics and nutrients of oceanic water in Saint Martin's Island during Cool winter and Pre-monsoon seasons are given in table 6.9 and table 6.10

Table 6.9 Measured physicochemical parameters of both seasons in the studied coastal waters

Sample ID	Cool Dry Winter Season					Pre-Monsoon Hot Season				
	pH	DO (mg/l)	Temp (°C)	TDS (g/l)	Salinity (psu)	pH	DO (mg/l)	Temp (°C)	TDS (g/l)	Salinity (psu)
S-1	8.10	7.75	24.85	20.16	26.21	7.95	6.26	26.10	23.55	30.62
S-2	8.11	7.95	25.40	20.21	26.37	8.15	6.13	26.20	23.50	30.66
S-3	8.11	7.80	24.61	20.13	26.18	8.22	6.10	26.00	23.62	30.72
S-4	8.13	8.36	24.76	20.15	26.22	8.2	6.49	26.10	23.71	30.85
S-5	8.18	7.59	24.98	20.08	26.15	8.2	6.37	26.20	23.87	31.09
S-6	8.16	6.63	25.14	20.02	26.07	8.13	6.39	26.70	23.82	31.02

S-7	8.14	7.03	24.22	20.16	26.23	8.3	6.48	26.30	23.36	30.39
S-8	8.15	7.82	24.26	20.04	26.09	8.26	6.47	26.30	23.40	30.47
S-9	8.16	7.84	24.22	19.97	25.98	8.18	6.71	26.40	23.36	30.39
S-10	8.14	7.93	24.27	20.09	26.15	8.2	6.60	26.20	23.29	30.32
S-11	8.14	8.00	24.33	20.18	25.98	8.2	6.74	26.10	23.43	30.16
S-12	8.13	8.66	24.16	20.12	26.05	8.14	6.63	26.20	23.29	30.15
Minimum	8.10	6.63	24.16	19.97	25.98	7.95	6.10	26.00	23.29	30.15
Maximum	8.18	8.66	25.40	20.21	26.37	8.30	6.74	26.70	23.87	31.09
SD	0.02	0.49	0.40	0.07	0.11	0.08	0.20	0.17	0.19	0.31

SD=Standard Deviation

Table 6.10 Measured nutrients concentration of both seasons in the studied seawater sample (in mg/l)

Sample ID	Cool Dry Winter Season					Pre-Monsoon Hot Season				
	Nitrate	Nitrite	Silicate	Ammonium	Phosphate	Nitrate	Nitrite	Silicate	Ammonium	Phosphate
S-1	0.615	0.146	8.995	0.315	0.187	0.312	0.093	7.654	0.115	0.118
S-2	0.627	0.136	8.665	0.287	0.173	0.297	0.097	7.673	0.132	0.103
S-3	0.667	0.139	8.773	0.261	0.131	0.314	0.107	7.704	0.112	0.081
S-4	0.763	0.143	8.641	0.254	0.163	0.384	0.119	7.024	0.137	0.138
S-5	0.568	0.121	8.304	0.255	0.163	0.388	0.112	7.259	0.174	0.133
S-6	0.586	0.144	8.189	0.206	0.154	0.393	0.115	7.881	0.211	0.128
S-7	0.679	0.126	8.536	0.252	0.133	0.399	0.102	7.772	0.218	0.142
S-8	0.722	0.125	8.764	0.224	0.146	0.301	0.097	7.559	0.214	0.138
S-9	0.769	0.138	8.912	0.351	0.236	0.312	0.103	8.346	0.219	0.127
S-10	0.654	0.133	8.795	0.347	0.194	0.305	0.098	8.345	0.186	0.132
S-11	0.781	0.164	9.001	0.313	0.154	0.309	0.087	8.090	0.142	0.105
S-12	0.745	0.173	8.814	0.305	0.184	0.314	0.089	7.780	0.092	0.098
Minimum	0.568	0.121	8.189	0.206	0.131	0.297	0.087	7.024	0.092	0.081
Maximum	0.781	0.173	9.001	0.351	0.236	0.399	0.119	8.346	0.219	0.142
Mean	0.673	0.139	8.66	0.275	0.165	0.336	0.012	7.757	0.163	0.120
SD	0.074	0.015	0.253	0.046	0.029	0.041	0.010	0.389	0.046	0.019

SD=Standard Deviation

The temperature exhibited the highest value in the Pre-monsoon season during March and the lowest value observed during October in the Cool winter season, with a considerable difference in the average temperature between Pre-monsoon and Cool winter season that numbered 26.23 ± 0.175°C and 24.60 ± 0.402°C. Solar direction, predominant wind actions, and wind-water interaction are the principal determinants of the mean temperature in coastal or island zones or neritic zone. Seasonal mean salinity based on data from 12 sites all across the Cool winter season and Pre-monsoon seasons was substantially distinguishable. During the Cool winter season, it was 26.14 ± 0.108 psu, which climbed up to a value of 30.570 ± 0.298 during the Pre-monsoon regardless of tidal conditions. A similar time schedule was approximately maintained to avoid tidal effects during sample collection. Compared to the Cool winter season, the Pre-monsoon season has a comparatively lower level of precipitation and a higher evaporation rate, which could lead to a significant rise in salinity. DO value during the Pre-monsoon season was slightly low (6.45 ± 0.200 mg/l) probably due to the greater abundance of planktonic species, and concurrent limited influxes of fresh water from adjacent areas. In contrast, it is was higher during Cool winter season (7.70 ± 0.491) might be due to the higher freshwater influx from the adjacent estuaries. There was no noteworthy pH fluctuation as per the season. The difference in mean value between seasons was confined to 0.04 despite the fact that the highest value was recorded in Pre-monsoon season, which might have resulted from the combined influence of similar turbidity and transparency of oceanic water in the study area. A substantially higher magnitude of TDS values was found in the Pre-monsoon season than in the Cool dry winter season, tentatively a consequence of sediment and anthropogenic influx from the adjacent run-off that valued 23.52 ± 0.191 whereas the Cool winter season showed a mean of 20.11 ± 0.068 g/l.

The mean values for all nutrient concentrations were the highest during the Cool winter season (Nitrate: 0.673 ± 0.074; Nitrite: 0.139 ± 0.015; Silicate: 8.66 ± 0.253; Ammonium: 0.275 ± 0.046; and Phosphate: 0.165 ± 0.029 mg/L) and during the Pre-monsoon season the values were slightly lower (Nitrate: 0.336 ± 0.041; Nitrite: 0.102 ± 0.010; Silicate: 7.757 ± 0.389; Ammonium: 0.163 ± 0.046; and Phosphate: 0.120 ± 0.019 mg/L). During both seasons silicates and nitrate are the prime contributor of the nutrients followed by ammonium and phosphate, respectively. The driving factors for nutrient concentration of the island are freshwater input (Achary et al., 2014) sediment inflow, nitrate oxidation (Rajasegar, 2003) and in some particular cases upwelling and downwelling of nutrient rich ocean water (Sarma et al., 2013). Based on the study on the distribution of physicochemical properties and nutrients both the seasons were suitable for cage and seaweed culture but Cool winter season was more suitable for seaweed and Pre-monsoon season was more suitable for cage culture.

The following figures illustrates the spatial distribution of the nutrients (NO_3, NO_2, SiO_4, NH_4, and PO_4) throughout the **pre-monsoon period (a) and cool winter season (b)**

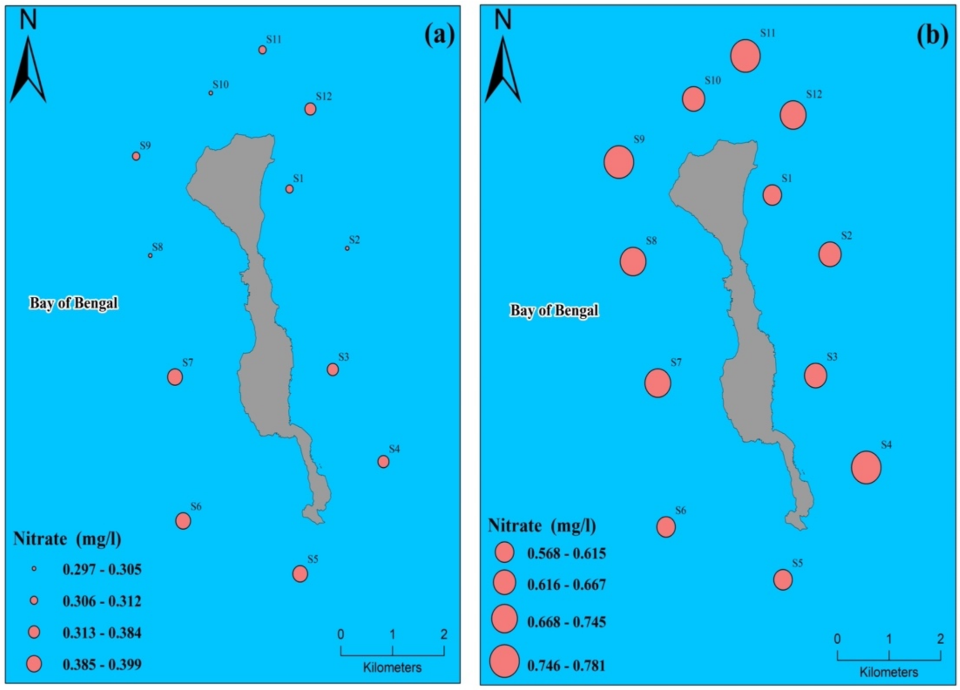


Figure 6.59 Seasonal variation and distribution of Nitrate (*NO_3*) in the coastal waters of St. Martin's Island

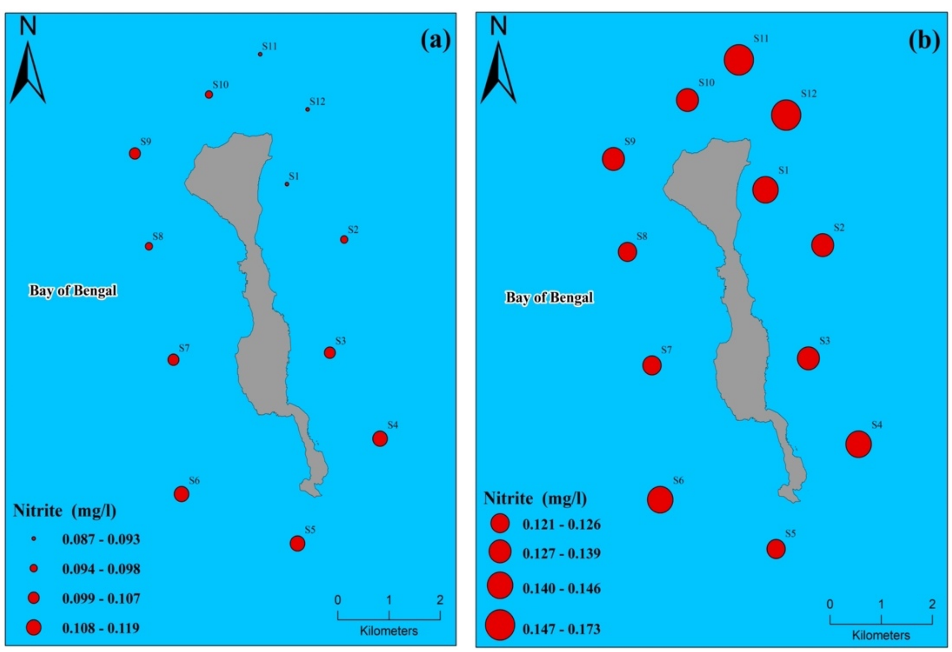


Figure 6.60 Seasonal variation and distribution of Nitrite (*NO_2*) in the coastal waters of St. Martin's Island

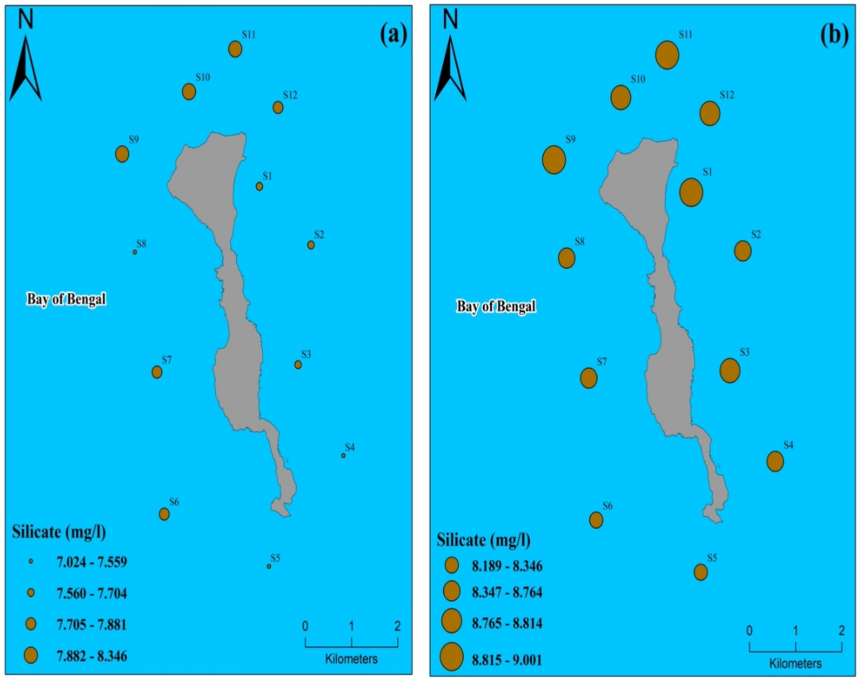


Figure 6.61 Seasonal variation and distribution of Silicate (SiO_4 *) in the coastal waters of St. Martin's Island*

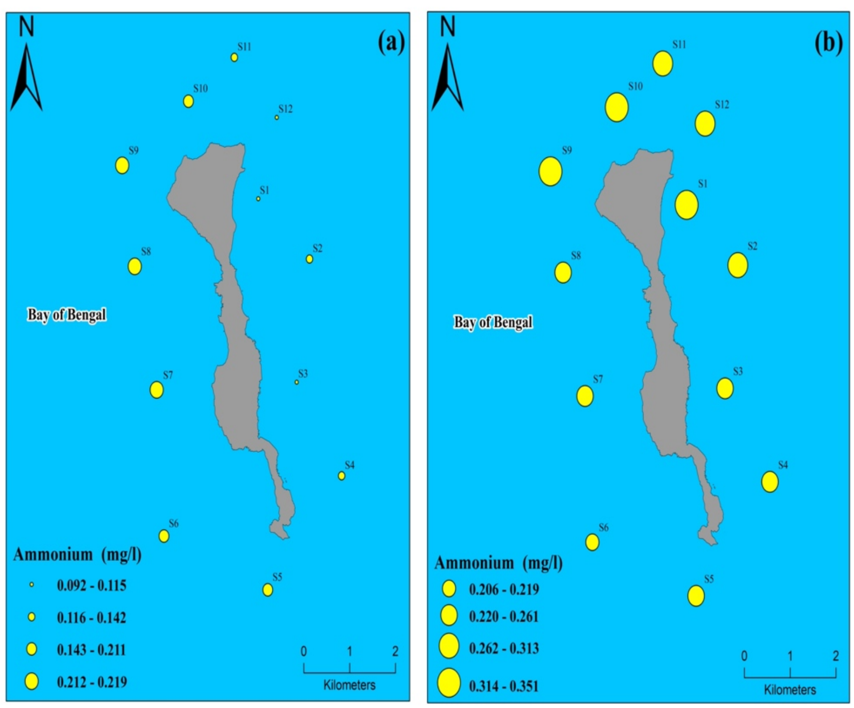


Figure 6.62 Seasonal variation and distribution of Ammonium (NH_4 *) in the coastal waters of St. Martin's Island*

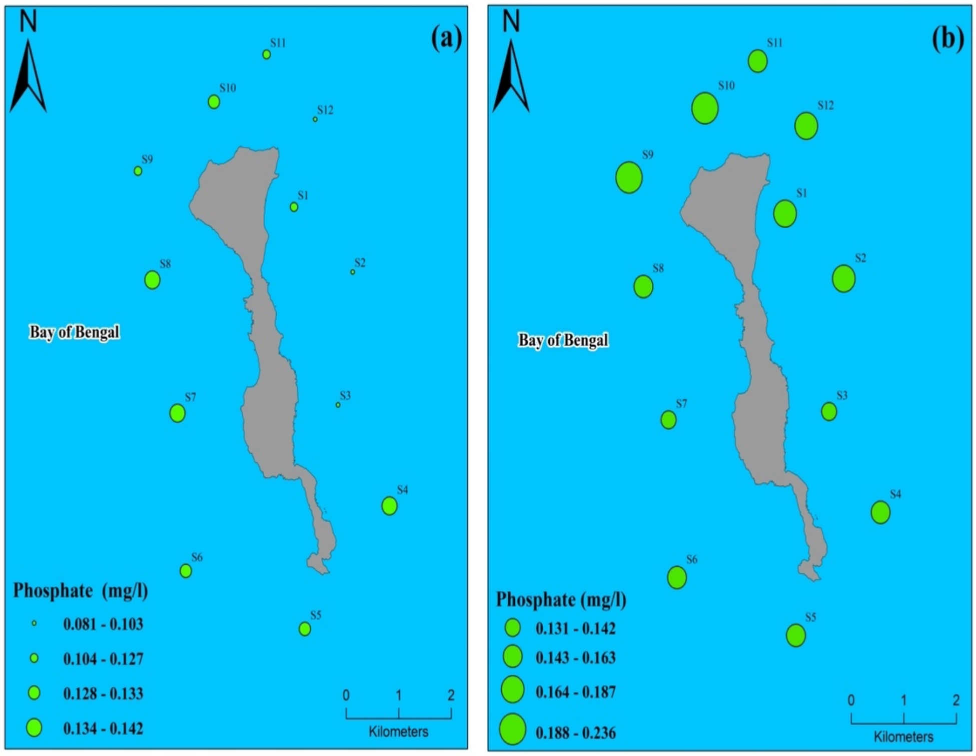


Figure 6.63 Seasonal variation and distribution of Phosphate (*PO*$_4$) in the coastal waters of St. Martin's Island

6.3.2 Source Identification of Nutrients by Statistical Analysis

In PCA, the number of PCs is equal to the number of original variables, and each PC incorporates all of the surface water quality metrics (Hasan et al., 2021). According to the principle of PCA, only those eigenvalues that are ≥1 is retained to construct the relevant dataset (Jackson, 1991). In this study, a scree plot was constructed using eigenvalues to show the number of PCs that were significant. The result of PCA for both seasons are showed in Table 6.11.

Table 6.11 The principal component analysis of observed physicochemical parameters

	Cool dry winter season			Pre-monsoon season	
Variable	PC1	PC2	PC3	PC1	PC2
pH	-0.439	**-0.787**	0.057	0.107	**0.644**
DO	**0.599**	0.294	0.300	-0.190	**0.638**
TDS	0.210	**0.884**	-0.189	**0.875**	-0.367
Salinity	-0.284	**0.840**	0.404	**0.919**	-0.316

Nitrate	**0.706**	-0.225	-0.370	**0.820**	0.298
Nitrite	**0.603**	-0.042	**-0.622**	**0.913**	0.082
Silicate	**0.919**	0.105	0.008	**-0.668**	0.308
Ammonium	**0.812**	-0.144	0.395	0.270	**0.802**
Phosphate	**0.550**	-0.480	0.560	0.452	**0.738**
Eigenvalue	3.346	2.507	1.285	3.889	2.435
% Variance	37.182	27.861	14.277	43.212	27.056
Cumulative %	37.182	65.042	79.319	43.212	70.268

Analyzing the physicochemical parameter and nutrient concentration, 3 PCs for the Cool winter season and 2 PCs for the Pre-monsoon seasons were identified. During the Cool dry winter season, 3 PCs were considered with a cumulative variance of 79.319% with a total eigenvalue of 7.138. For the Pre-monsoon seasons, 2PCs contributed about 70.268% of total variance, with a total of 6.315 eigenvalues. During the Cool dry winter season, PC1 contributed to about 37.182% of the total variance, which signify that the contributing nutrients are the most influential. During the Cool winter season, silicate (0.919), ammonium (0.812), nitrate (0.706), nitrite (0.603), DO (0.599) and phosphate (0.550) showed positive and higher loading. The output data suggests that the nutrients may be accumulated from similar sources of origin that are attributed to the oceanic water of Saint Martin's Island. Significantly higher loadings for this association (PC1) reflect the heavy influx of freshwater into the marine environment during Cool dry winter season, increasing nitrogenous nutrients, silicates, and DO levels (Achary et al., 2014). Furthermore, significant amounts of silicate, phosphate, and DO indicate the presence of diatoms and other planktonic species that thrive in phosphate and silicate-rich environments. That finally contributed to improving the state of dissolved oxygen (Achary et al., 2014). During Cool dry winter season, plankton communities proliferate, which may contribute to the above conditions. In the case of PC2, the parameters, particularly, TDS (0.884), salinity (0.840), and pH (-0.787) showed significant loading. Salinity declined during Cool dry winter season is a result of dilution of coastal water from heavy rainfall during monsoon and influx of freshwater from the Meghna, Matamuhuri, and Bakkhali estuaries of Bangladesh and as well as influx from upstream of Myanmar region.

In PC3, the parameter nitrite (-0.622) shows significant negative loading which indicate the different sources of origin. That might be the anthropogenic or upwelling from the deep water. Additionally, higher negative loading may be caused by ammonia from nitrogen being oxidized to yield nitrite (Rajasegar, 2003) in the studied region. From the analysis of the parameter's value in the Pre-monsoon season, considerable discrepancies in nutrient sources were identified. In the PC1 during the Pre-monsoon season, parameters like salinity (0.919), nitrite (0.913), TDS (0.668), nitrate (0.820), showed significant positive loading, whereas silicate (-0.668) showed significant negative loading. The higher loading of salinity and TDS could be linked to the lack of rainfall and increased evaporation, as well as to the dominance of neritic water (Rajasegar, 2003). Higher loadings of nitrite, nitrate, and silicates were induced by high salinity that might be caused due to active oceanic processes, primely upwelling, vertical mixing through cyclones, or Ekman pumping (Sarma et al., 2013). Low levels were reported during Pre-monsoon periods owing to its use by phytoplankton, as shown by elevated photosynthetic activity, as well as by the predominance of neritic water.

For PC2, parameter ammonium (0.802), phosphate (0.738), pH (0.644), and DO (0.638) show high positive loadings. High ammonia and phosphate loadings during the Pre-monsoon season (April) suggest the occurrence of minor coastal upwelling and dilution of ocean water (Achary et al., 2014). However, salinity showed no significant load with ammonium and phosphate in PC2 but their concentration increased slightly with the increasing trend of salinity during Pre-monsoon (Sarma et al., 2013). It is suggested that phosphate was liberated from the sediment as a result of the turbulent action caused by the high winds that prevailed during this time period (Chandran & Ramamoorthi, 1984; Choudhury & Panigrahy, 1991). The large differences seen may be caused by processes like phosphate adsorption and desorption and the buffering effect of sediment in different environmental conditions (Govindasamy et al., 2000). Ammonia showed high loading during Pre-monsoon period that might be due to the anthropogenic input from the adjacent land area (Achary et al., 2014).

6.3.3 Hierarchical Cluster Analysis

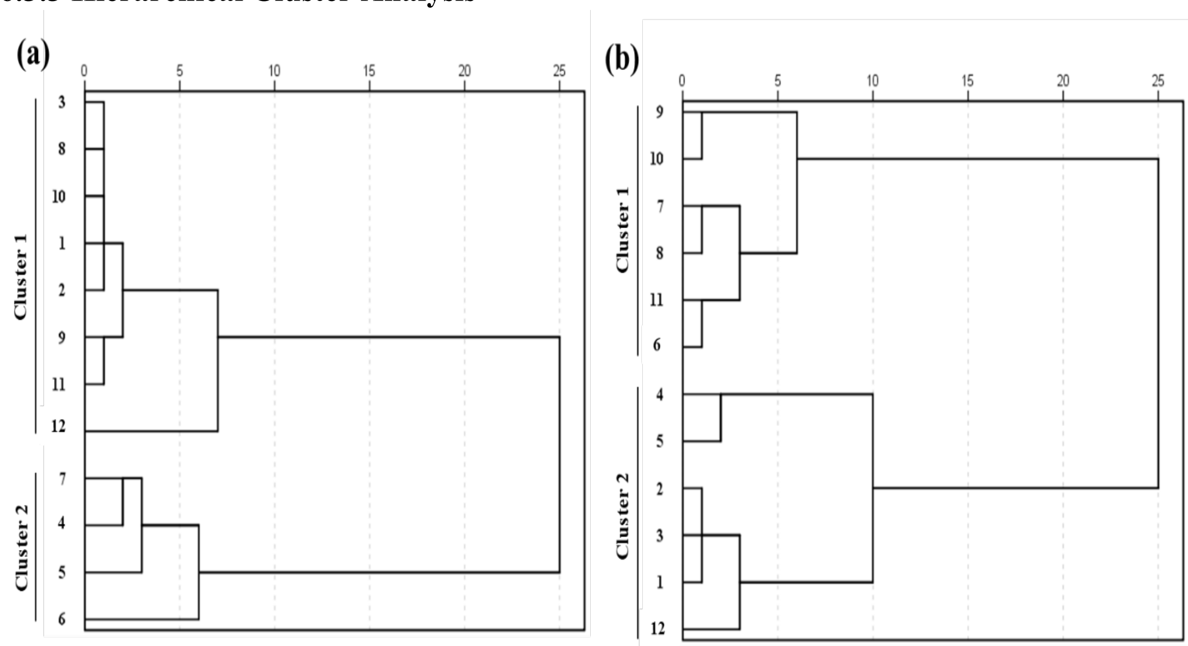


Figure 6.64 Dendrogram showing the hierarchical clustering of the seawater sampling sites: (a) Cool dry winter season; (b) Pre-monsoon season

The HCA was used to determine the spatiotemporal variability and similarity of surface seawater samples based on the concentrations of several physicochemical parameters (Hasan et al., 2021), which classified 12 surface seawater samples into two major clusters for both seasons. Table 6.9 presented the average values of the seawater parameters from the Q-mode hierarchical clustering for the both seasons.

In Cool winter season, Cluster 1 and 2 comprises about 66.66% and 33.33% of the sampling sites, respectively. Cluster 1 is made up of highest average concentration of physicochemical parameters except salinity and TDS than cluster 2. Samples in cluster 1 (S1, S2, S3, S8, S9, S10, S11, and S12) are predominantly found in the northern and northwestern part of the study area (Figure 5.13) close to the Naf River estuary which suggested the active influence of freshwater influx during the beginning of Cool winter season. In cluster 1, regardless of their location, a considerably higher concentration of DO, nitrate, nitrite, silicate, ammonium, and phosphate are seen, where these variables display a higher loading in PC1 of Cool winter season (Table 6.11).

In Pre-monsoon season, Cluster 1 and 2 comprises about 50% and 50% of the sampling sites, respectively. Cluster 1 has a greater average content of TDS, salinity, nitrate, nitrite, silicate, and ammonium than cluster 2. Samples in cluster 1 (S6, S7, S8, S9, S10, and S11) are mainly found in the western and northwestern part of the study area (Figure 5.13), which is located to seaward side indicating might be the influence of mild upwelling and vertical mixing. In the Principal Component Analysis, the parameters of Cluster 1 and Cluster 2 are comparable to those in PC1 and PC2 of the Pre-monsoon season (Table 6.12), indicating a similar source of origin.

Table 6.12 Mean values of Nutrients concentration derived from cluster analysis of the studied coastal water

	Cool dry winter season		Pre-monsoon season	
Parameters	**Cluster 1 (n=8)**	**Cluster 2 (n=4)**	**Cluster 1 (n=6)**	**Cluster 2 (n=6)**
pH	8.130	8.153	8.143	8.212
DO	7.806	7.478	6.367	6.528
TDS	20.103	20.113	23.590	23.443
Salinity	26.127	26.167	30.682	30.458
Nitrate	0.698	0.649	0.337	0.335
Nitrite	0.144	0.134	0.103	0.100
Silicate	8.840	8.418	7.999	7.561
Ammonium	0.300	0.242	0.198	0.127
Phosphate	0.176	0.153	0.112	0.129

n= Number of sea surface water samples in each cluster

6.3.4 Correlation Analysis for physicochemical parameters and nutrients

The origin, connection, and movement of physicochemical parameters may be inferred from their correlations (Arumugam, 2016). Table 6.12 shows the correlation coefficient of nine (9) physicochemical parameters of the surface seawater for two different seasons.

Table 6.13 Correlation analysis of the studied physicochemical parameters and nutrients

	pH	DO	TDS	Salinity	Nitrate	Nitrite	Silicate	Ammonium	Phosphate
CDW (n=12)									
pH	1								
DO	-0.307	1							
TDS	**-0.688**	0.296	1						
Salinity	**-0.524**	0.174	**0.602**	1					
Nitrate	-0.054	0.467	-0.015	-0.490	1				
Nitrite	-0.330	0.018	0.250	-0.429	0.464	1			
Silicate	**-0.533**	**0.538**	0.233	-0.217	**0.613**	0.432	1		
Ammonium	-0.220	0.373	0.062	-0.209	0.329	0.325	**0.723**	1	
Phosphate	0.100	0.217	-0.398	-0.282	0.191	0.172	0.380	**0.764**	1
PM (n=12)									
pH	1								
DO	0.265	1							
TDS	-0.172	-0.319	1						
Salinity	-0.138	-0.466	**0.943**	1					
Nitrate	0.241	0.141	**0.604**	**0.584**	1				
Nitrite	0.213	-0.128	**0.749**	**0.826**	**0.728**	1			
Silicate	-0.009	0.129	**-0.616**	**-0.609**	-0.459	-0.481	1		
Ammonium	0.471	0.148	-0.035	0.093	0.345	0.304	0.294	1	
Phosphate	0.248	0.394	0.085	0.201	**0.534**	0.387	-0.152	**0.746**	1

In Cool winter period, DO and nitrate shows a strong positive correlation with silicate. Significant positive correlation between DO and silicate; silicate and nitrate suggest their sources of origin may be similar. For the observed higher values during the Cool dry winter season, the discharge of fresh water from the Naf River estuary rich in silicate could be responsible.

Silicate values showed poor correlation with salinity whereas significant correlation between DO and silicates indicates that land derived weathered silica rich fresh water might be the main sources of silicates in the present studied coastal region. In addition, high silicate concentrations suggest that nutrients were transported mostly through land drainage (Sarma et al., 2013). Furthermore, silicate had a significant positive correlation with ammonium and it showed a strong

positive correlation with phosphate which indicates weathering of rock silicates that dissolve alkali metal phosphate, which are transported to coastal waters, can also contribute to increased values (Achary et al., 2014). Significant strong positive correlation among salinity and the nutrients were observed during Pre-monsoon season. The correlation between nutrients and salinity reveals the sources of nutrients in the coastal water. The strong correlation between nutrients and salinity indicates vertical mixing, coastal upwelling, and Ekman pumping in the Pre-monsoon period (Sarma et al., 2013). Whereas decreasing salinity with increasing nutrients concentration are indicative of riverine sources (Sarma et al., 2013).

6.4 Seasonal Variation and Spatial Distribution of Heavy Metals in the Coastal waters of St. Martin's Island

Seasonal difference Observations of heavy metals in the coastal waters adjacent to St. Martin's Island in the Bay of Bengal were done to determine their impact on mariculture. Evaluation of heavy metal contamination, pollution evaluation indices, health index, and statistical methods were incorporated for this aim. From 12 different sampling locations along the island's edge, two seasons- the Cool Dry Winter Season and the Pre-Monsoon Hot Season were considered in this regard. The study observed some distinct variation between two seasons whereas the concentration of the heavy metal was higher in the Pre-monsoon hot season in comparison to the Cool dry winter season. Heavy metals, namely Pb, Cu, As, Cr, Cd and Zn, were considered to understand the broader geo-chemical perspectives along with their ecological and human health hazards on the island. Mercury (Hg) was also taken into account, however following the laboratory test, this parameter was ignored because the amount of mercury in the sample that was collected was unreadable and insignificant. Heavy metal Pollution Index (HPI) and Heavy metal Evaluation Index (HEI) showed that majority of locations are significantly higher in the Pre-monsoon hot season, even though no significantly higher value was detected in the Cool winter season. The Nemerow Index, the Total Ecological Risk Index (TERI), suggested that the heavy metal contamination ranged between severely to moderately polluted and low to moderate category, respectively.

6.4.1 Seasonal Variation of Heavy Metal in Coastal waters of St. Martin's Island

Concentration (µg/L) of heavy metals in the seawater samples of the Saint Martin's Island during Cool winter and pre-monsoon seasons, are given in Table 6.14

Table 6.14 Heavy metals concentration in the coastal water of St. Martin's Island during Cool winter and pre-monsoon seasons

Sample Id	Pre-monsoon hot season						Cool dry winter season					
	Pb	Cu	As	Cr	Cd	Zn	Pb	Cu	As	Cr	Cd	Zn
S-1	59.28	25.72	0.95	4.58	3.29	47.81	25.52	22.94	1.06	2.07	4.71	49.34
S-2	107.83	27.90	1.09	2.06	6.49	58.04	23.89	25.20	0.96	1.56	3.07	27.87
S-3	80.67	23.67	0.99	1.72	4.69	62.67	19.21	22.93	1.14	2.09	2.89	10.12
S-4	157.59	26.62	0.92	2.72	8.54	51.99	40.41	21.92	1.27	5.76	1.27	11.65
S-5	132.13	29.61	1.34	4.75	11.42	60.75	22.74	24.87	1.58	7.07	1.91	24.76
S-6	85.42	27.65	0.65	3.52	9.80	44.39	13.67	22.98	0.85	1.08	4.68	13.26
S-7	76.56	29.67	1.26	0.88	15.49	45.09	37.19	26.52	0.72	0.68	5.20	36.08
S-8	59.64	23.47	0.91	1.38	6.09	32.51	40.52	21.21	0.59	0.76	3.22	16.92
S-9	48.57	24.67	0.82	2.56	4.53	41.68	20.51	23.09	1.17	1.87	5.09	17.67
S-10	33.53	27.69	0.74	3.89	2.89	38.38	12.86	25.97	0.93	3.79	4.80	8.05
S-11	21.91	29.56	1.13	6.03	0.84	24.43	16.67	26.52	1.66	6.99	4.68	20.78
S-12	58.77	33.51	1.09	7.62	2.31	26.67	25.72	23.70	0.78	2.68	3.21	16.67
Minimum	21.91	23.47	0.65	0.88	0.84	24.43	12.86	21.21	0.59	0.68	1.27	8.05
Maximum	157.59	33.51	1.34	7.62	15.49	62.67	40.52	26.52	1.66	7.07	5.20	49.34
Mean	76.825	27.478	0.990	3.475	6.365	44.534	24.909	23.987	1.0591	3.033	3.727	21.097
SD	37.91	2.78	0.19	1.92	4.08	12.09	9.28	1.71	0.31	2.23	1.26	11.44

The samples analysis enumerated that the mean value of the Pre-monsoon hot season (Pb: 76.825 ± 37.91; Cu 27.478 ± 2.78; As: 0.990 ± 0.19; Cr: 3.475 ± 1.92; Cd: 6.365 ± 4.08; Zn: 44.53416667 ± 12.09 µg/L) was considerably higher in concentration than the mean value of heavy metals during the Cool winter season (Pb: 24.909 ± 9.28; Cu 23.987 ± 1.71; As: 1.0591 ± 0.31; Cr: 3.033 ± 2.23; Cd: 3.727 ± 1.26; Zn: 21.0975 ± 11.44 µg/L). The prime reason for higher concentrations of heavy metals during the Pre-monsoon hot season may be due to lower freshwater influx from upstream, a higher evaporation rate, and lower precipitation in the study area. Usually, the heavy influx from the upstream runoff gets mixed with the seawater, that dilutes the concentration; afterward, the heavy influx carries the heavy metals to the deep sea. However, the sources of the metals are numerous, whereas shipbreaking industries, battery production factories, and frequent building materials, along with lighter ships, cargo ships, and vessel ships, are the prime anthropogenic sources in the study area (A. B. Hasan et al., 2013). In some cases, higher concentrations of As may accumulate in the study area from the weathered parent rock, as if most of the river that ultimately discharged in the Bay of Bengal originated in the Himalayan Mountain belt (Kibria et al., 2016; Rushinadha Rao et al., 2016)

The following figure illustrates the spatial distribution of the Heavy metal (Pb, Cu, As, Cr, Zn and Cd) throughout the **pre-monsoon period (a)** and **cool winter season (b)**

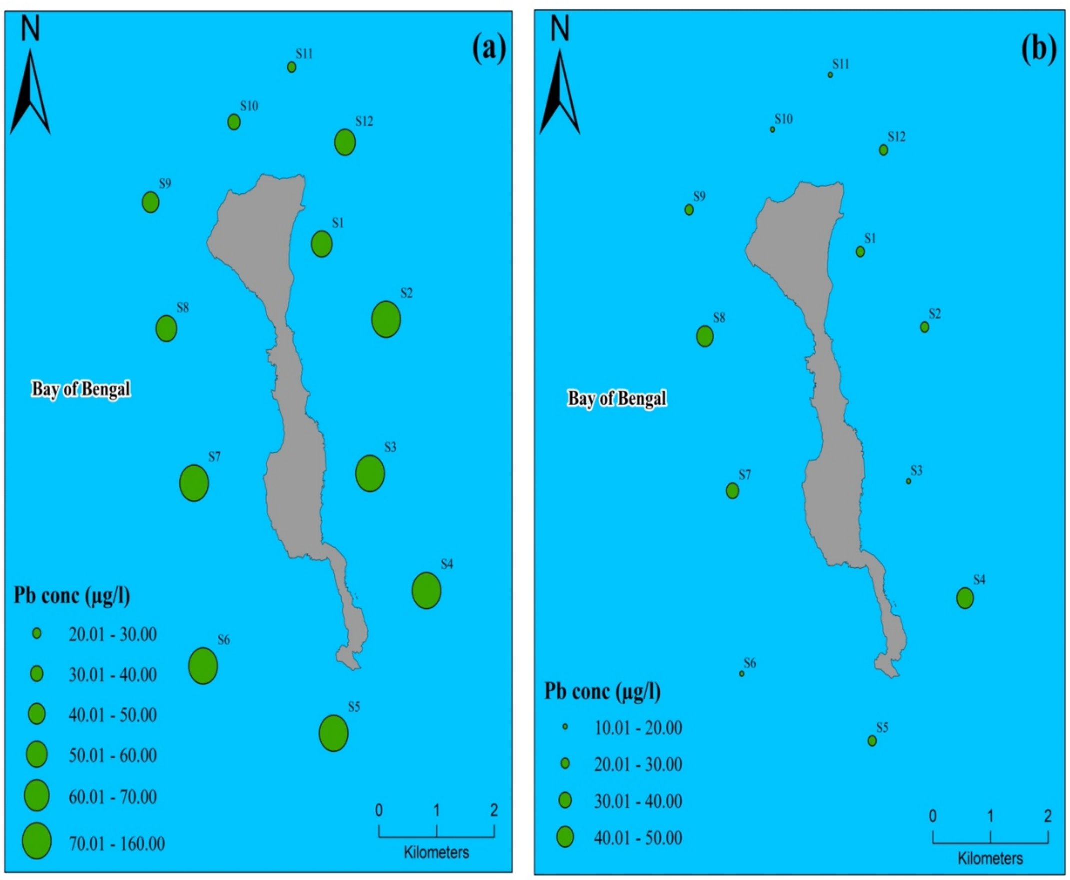


Figure 6.65 Seasonal variation and distribution of Lead (Pb) in the coastal waters of St. Martin's Island

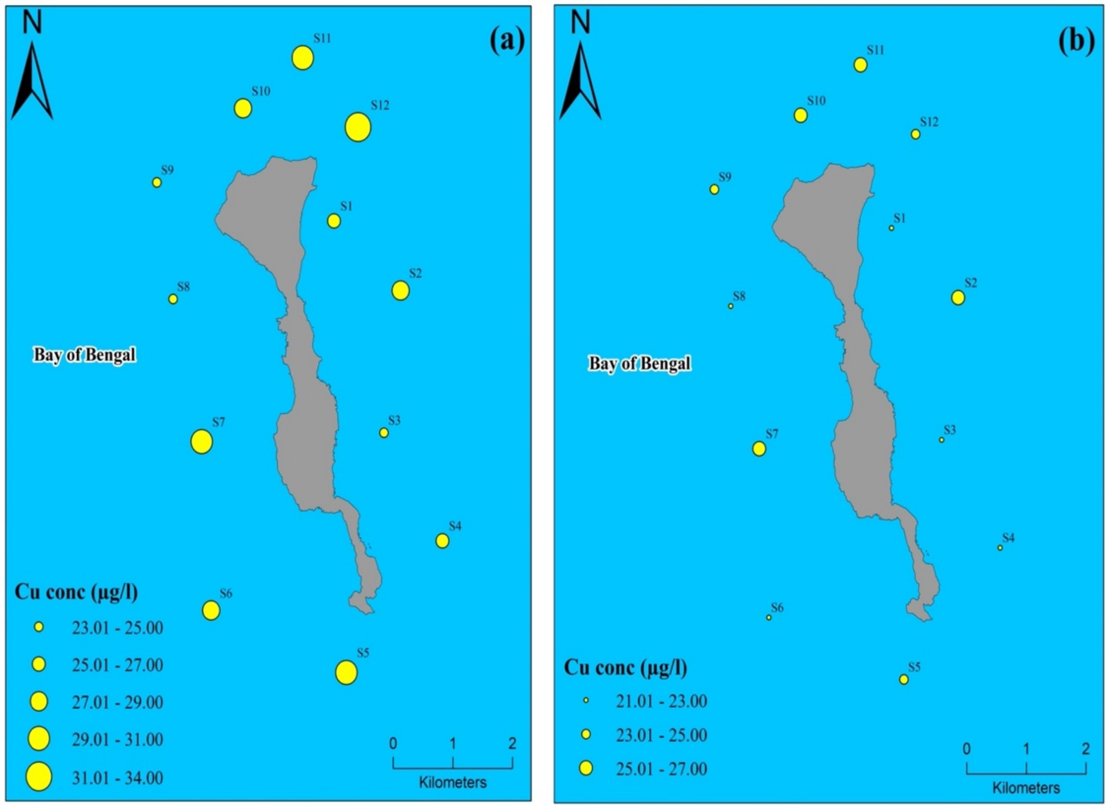


Figure 6.66 Seasonal variation and distribution of Copper (Cu) in the coastal waters of St. Martin's Island

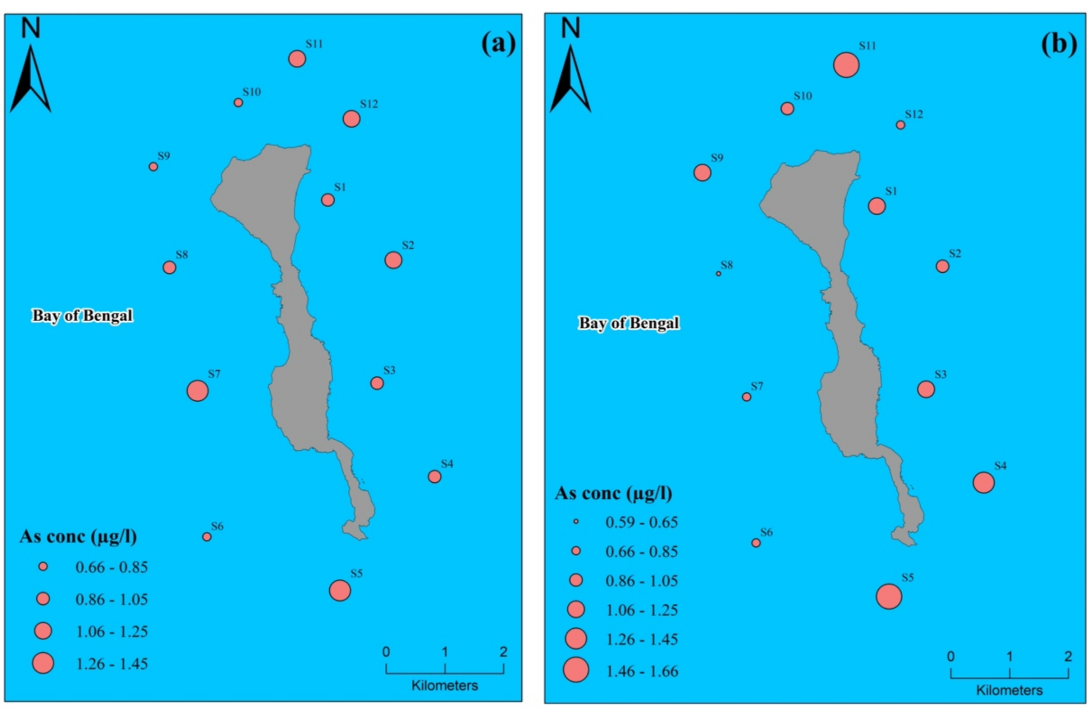


Figure 6.67 Seasonal variation and distribution of Arsenic (As) in the coastal waters of St. Martin's Island

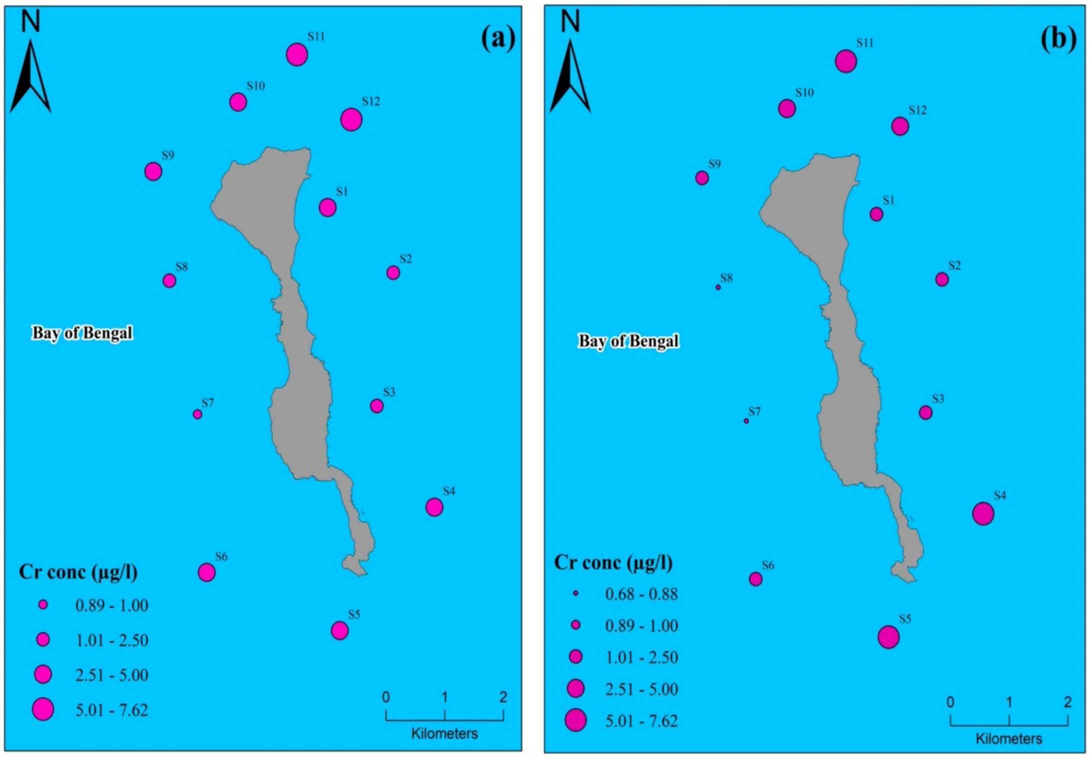


Figure 6.68 Seasonal variation and distribution of Chromium (Cr) in the coastal waters of St. Martin's Island

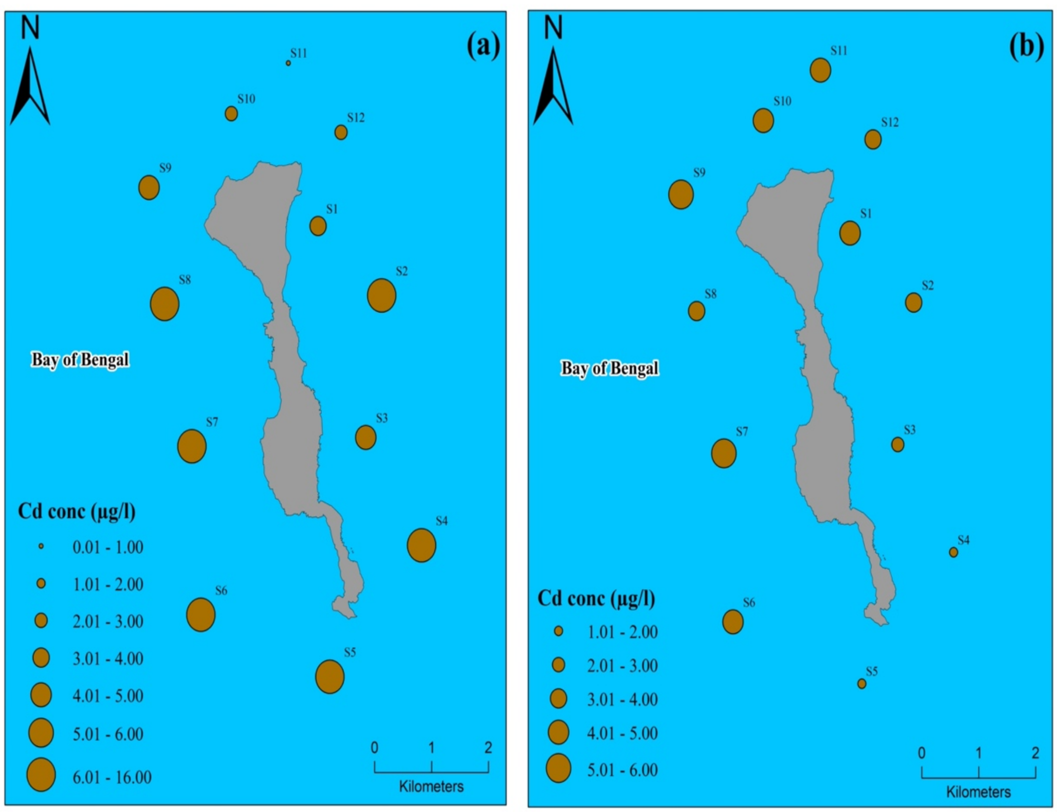


Figure 6.69 Seasonal variation and distribution of Cadmium (Cd) in the coastal waters of St. Martin's Island

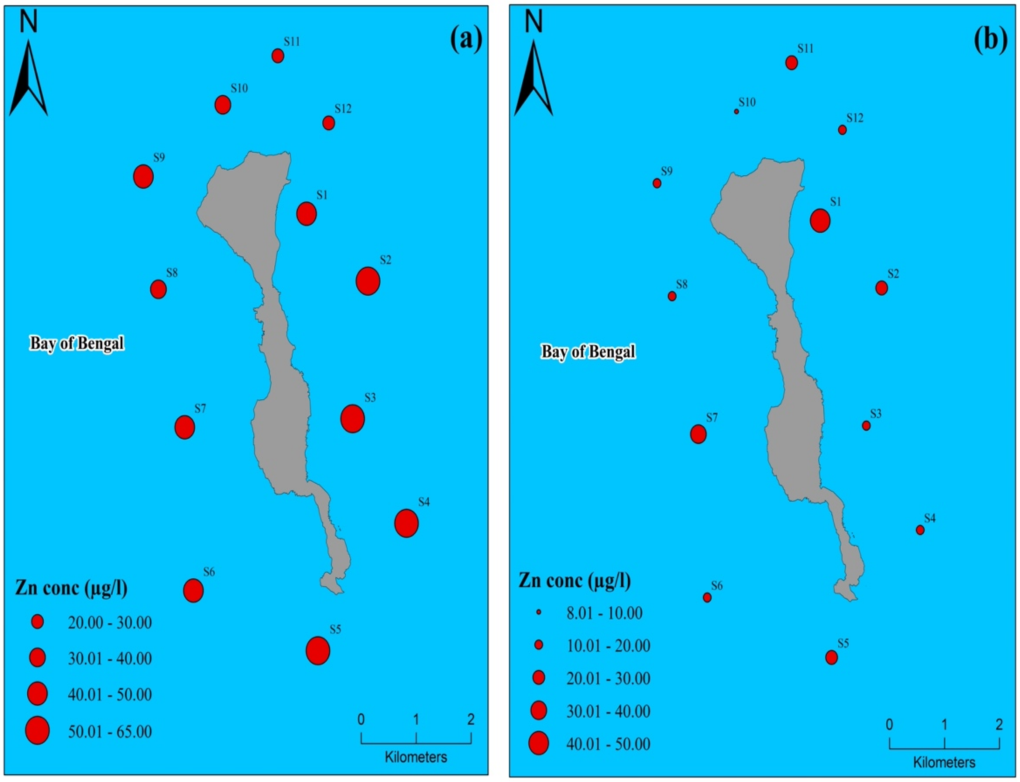


Figure 6.70 Seasonal variation and distribution of Zinc (Zn) in the coastal waters of St. Martin's Island

6.4.2 Heavy Metal Indices

The results of the heavy metal indices for both seasons have been enumerated and displayed in Table 6.15.

Table 6.15 Heavy Metal Indices in Pre- Monsson and Cool Winter season in the Coastal waters adjacent to St. Martin's Island

Sampling station / Index	Pre-monsoon hot season				Cool dry winter season			
	HPI	HEI	NPI	TERI	HPI	HEI	NPI	TERI
S1	31.38	9.62	1.41	94.04	86.19	6.59	1.04	67.02
S2	140.44	14.48	1.89	162.66	41.40	5.87	0.98	56.09
S3	89.43	11.49	4.04	122.58	39.23	4.92	1.72	49.02
S4	197.90	18.84	4.98	224.02	74.46	6.66	2.51	60.78

S5	268.42	17.99	4.30	218.05	62.45	6.02	0.79	49.08
S6	227.81	13.11	4.31	159.87	90.75	4.77	1.72	53.99
S7	407.45	13.48	4.78	185.84	109.03	7.60	1.03	82.73
S8	131.30	9.35	3.68	109.12	51.29	6.58	2.51	71.11
S9	78.99	8.54	2.50	89.69	98.15	5.62	1.76	63.74
S10	29.57	7.32	2.16	66.53	78.43	5.20	1.94	55.86
S11	87.85	6.08	2.21	43.82	78.80	6.15	2.01	60.35
S12	55.62	10.04	3.01	91.83	39.19	5.78	1.66	57.93
Maximum	407.45	18.84	4.98	224.02	109.03	7.60	2.51	82.73
Minimum	29.57	6.08	1.41	43.82	39.19	4.77	0.79	49.02
Average	145.51	11.69	3.27	130.67	70.78	5.98	1.64	60.64
SD	107.5897	3.83891	1.17229	56.26208	22.8956	0.7764	0.5514	9.18164

6.4.3 Pollution Evaluation Indices

6.4.3.a Heavy Metal Pollution Index (HPI)

The analysis of the results from the HPI index for both Pre-monsoon hot season and Cool winter season sampling points revealed some significant findings. The Pre-monsoon results showed a range of values between 29.57 and 407.45. The results showed significant variation, with samples 5 and 7 recording the highest values of 268.42 and 407.45, respectively. However, it was noted that considerable number about 50% of the sampling points were beyond the HPI threshold limit of 100 (Edet & Offiong, 2002) during the Pre-monsoon season. However, during the Cool dry winter season none of the sampling points showed higher values than the threshold value of 100 except for the sampling point S7. The significantly higher HPI value in both seasons for S7 might be due to the influx of heavy metals from the adjacent upstream area. Otherwise, considerably lower values of HPI in the Cool winter season might be induced by a comparatively higher precipitation rate during the monsoon and higher fresh water input from the upstream drainage system.

6.4.3.b Heavy Metal Evaluation Index (HEI)

Apart from HPI, the heavy metal evaluation index (HEI) was calculated due to an explicit understanding of the heavy metal concentration around the study area. From the study, it was found that the HEI value varied from 6.08 to 18.84 during Pre-monsoon season and from 4.77 to 7.60 during Cool winter season (Table 6.19), with a mean value of 11.69 and 5.98, respectively. The study found that all the sampling points during the Cool dry winter season (Edet & Offiong, 2002; Mohanta et al., 2019) and about 50% of the total sampling points during the Pre-monsoon had medium level of HEI values ((Edet & Offiong, 2002).

6.4.3.c Nemerow Pollution Index (NPI)

The Nemerow Pollution Index is incorporated to evaluate the heavy metal contamination level and water quality of a given area. In general, a higher value of the index indicates lower water quality. The study found that during the Pre-monsoon season, the Nemerow Pollution Index ranged from 1.41 to 4.98, with an average value of 3.27. Concurrently, during the Cool dry winter season, the Nemerow Pollution Index values fluctuated from warm to moderate pollution degrees, with a range of 0.79 to 2.51 and an average value of 1.64. In comparison to the NPI critical value, it can be stated that none of the sample stations are significantly contaminated and that all of them are acceptable for the survival and flourishing of marine organisms.

6.4.3.d Total Ecological Risk Index (TERI)

Excessive concentrations of heavy metals that are not significantly indispensable might interrupt the delicate balance of the ecosystem and cause hazardous issues subsequently. A potential ecological risk index may thus be a considerable tool to delineate the degree of risk propagated in marine ecosystems due to the simultaneous heavy metal deposition in the sediment (Rahman et al. 2014). The analyzed level of Total ecological risk index and potential ecological risk index have been stated in Table 6.19. Upon the conclusion of the comprehensive assessment, the range of TERI for both the Pre-monsoon and Cool winter season is 43.82 to 224.02 and 49.02 to 82.73, respectively, which denotes that the samples in the study area lied between the low and moderate risk classes for the Pre-monsoon and all samples lied in the low-risk category for the Cool winter season. The descending order of TERI for Pre-monsoon and Cool winter season are: S4>S5>S7>S2>S6>S3>S8>S1>S12>S9>S10>S11and S7>S8>S1>S9>S4>S11>S12>S2>S10>S6>S5>S3, respectively.

The prime cause for significant level of heavy metal contamination could be due to water-vehicle waste, oil-leakage from lighter ships, cargo ships, fertilizer use on upstream (*ATSDR*, 2004.; M. S. Islam & Hoque, 2014), waste disposal sites (M. S. Islam & Hoque, 2014) in the coastal area that brought by drainage system.

6.4.4 Source Identification of Heavy Metals by Statistical Analysis

From the PCA analysis of heavy metals in the study area in Cool Winter and Pre-monsoon hot season portrayed significant insights about the source and accumulation of heavy metal (Prasanna et al., 2012). The analysis showed 2 PCs for Pre-monsoon season and 3PCs for north east monsoon season. During the Pre-monsoon season, 2 PCs were considered with a cumulative variance of 75.21% with a total eigenvalue of 4.51. For the Cool dry winter season, 3PCs contributed about 86.288% of total variance, with a total of 5.177 eigenvalues.

Table 6.16 The Principal Component Analysis of Heavy Metals in the Seawater samples during Pre-monsoon hot season

Variable	PC1	PC2
Pb	0.783	0.337
Cu	-0.383	0.862
As	0.188	0.793
Cr	-0.748	0.485
Cd	0.770	0.337
Zn	0.856	0.022
Eigenvalue	2.68	1.83
% Variance	44.65	30.56
Cumulative %	44.65	75.21

Table 6.17 The Principal Component Analysis of Heavy Metals in the Seawater samples during Cool dry winter season

Variable	PC1	PC2	PC3
Pb	-0.443	-0.602	0.546
Cu	0.419	0.709	0.204
As	0.924	-0.037	0.185
Cr	0.934	-0.207	0.162
Cd	-0.288	0.881	-0.092
Zn	-0.227	0.359	0.850
Eigenvalue	2.231	1.815	1.131
% Variance	37.181	30.257	18.85
Cumulative %	37.181	67.438	86.288

Around 37.181% of the variance was attributed to PC1, which accounted for the majority during the Cool dry winter season. The loadings for PC1 indicate that Pb has a negative correlation (-0.443) with this principal component, whereas the other variables, namely Cu, As, Cr, Cd, and Zn, have positive correlations. This suggests that Pb has an inverse relationship with the other variables and is therefore not a major contributor to PC1. PC1 might be caused by the leaching of metals carried by the combined sediment of the upstream water inflow (Prasanna et al., 2012). The loadings for PC2 indicate that Cd has the highest positive correlation (0.881) with this principal component, followed by Cu (0.709) and Zn (0.359). This suggests that these three variables are the main contributors to the variability captured by PC2. Cd, Cu, and Zn might be propagated from anthropogenic source like shipping repairing sites, corrosive plating of ships and lighter ships (Prasanna et al., 2012). The loadings for PC3 indicate that Zn has the highest positive correlation (0.85) with this principal component, followed by Cu (0.204) and As (0.185), denoting atmospheric exposure that dispersed from the nearby industrial region into the seawater (Steinnes & Henriksen, 1993). Similarly, for the Pre-monsoon hot season, PC1 accounts for 44.65% of the total variance and PC2 accounts for 30.56% of the total variance, which contributed about 75.21% of the total variance. The simulated dataset showed that the loading of Pb on PC1 is 0.783, which means that Pb is strongly associated with PC1.

Similarly, Cu and Cr have a negative loading on PC1 (-0.383), which means that they are negatively associated with PC1. A significantly higher negative loading of Cr (-0.748) might be due to the water influx transported by the river system to the Bay of Bengal (Hasan et al., 2022). In the case of PC2, all the components have positive loading, where Cu and As contributed the highest loading of.862 and 0.793, respectively. This signifies the uniform source, which might be solely anthropogenic.

6.4.5 Correlation Analysis of Heavy Metals of the Coastal waters

Pearson's correlation among six different heavy metals were been executed and represented in the Table 6.18 and Table 6.19. Pearson's correlation was performed in this study in order to find explicit insight about the source and association extent among the heavy metals.

Table 6.18 Pearson's Correlation of Heavy Metals during Pre-monsoon hot season

	Pb	Cu	As	Cr	Cd	Zn
Pb	1.000					
Cu	-0.004	1.000				
As	0.245	0.471	1.000			
Cr	-0.264	0.674	0.126	1.000		
Cd	0.601	0.081	0.319	-0.525	1.000	
Zn	0.710	-0.334	0.178	-0.480	0.468	1.000

Table 6.19 Pearson's Correlation during of Heavy Metals Cool dry winter season

	Pb	Cu	As	Cr	Cd	Zn
Pb	1.000					
Cu	-0.377	1.000				
As	-0.326	0.261	1.000			
Cr	-0.158	0.286	0.863	1.000		
Cd	-0.400	0.393	-0.257	-0.422	1.000	
Zn	0.233	0.205	-0.017	-0.176	0.285	1.000

The correlation among the heavy metals during the inter-monsoon is that Pb has a very high positive correlation with Zn (0.710) and Cd (0.601), which signify a higher association level or similar source. As has a moderate positive correlation with Pb (0.245), Cu (0.471), and Cd (0.319). Cr has a moderately negative correlation with Pb (-0.264) and a strong positive correlation with Cu (0.674); this suggests that Cr and Cu have similar anthropogenic sources (Liu et al., 2003). Cd has a strong positive correlation with Zn (0.468) and a moderate positive correlation with As (0.319) and Pb (0.601). The findings demonstrate that Pb and Cd have a unique source to some extent that might be battery production industries and ship cutting industries on the adjacent coastal area (Ali et al., 2016; Chen et al., 2012; M. S. Islam et al., 2015; Jiang et al., 2014; Li et al., 2009; Suresh et al., 2012). Moreover, Zn has a strong positive correlation with Pb (0.710) and a strong negative correlation with Cu (-0.334). Cu and Cr may be induced by the rapid urbanization along the shoreline, or on the coastal area to be precise, as if Cu and Cr are vital building materials and electrical components.

On the other hand, Pearson's correlation during the Cool dry winter season found a negative correlation between Cu and Pb (-0.377), which suggests that an increase in Cu leads to a decrease in Pb concentration during and immediate after the monsoon season. As and Cd also show negative correlations with Pb (-0.326 and -0.400, respectively). There is a moderately positive correlation between As and Cr (0.863), while Cd shows a negative correlation with both As and Cr (-0.257 and -0.422, respectively). Zn has a weak positive correlation with Cu and Pb (0.205 and 0.233, respectively), while showing a weak negative correlation with Cr and Cd (-0.176 and 0.285, respectively). The negative correlation between Cu and Pb could be due to the fact that these two metals have different sources and associations in the environment. The moderately positive correlation between As and Cr suggests that they may have similar sources. Overall, the research observed that there were much less sources of heavy metals accumulation during the pre-monsoon than during the cool winter season, which is also indicative of the impact of fresh water intake through the nearby estuaries (Hasan et al., 2022).

6.5 Feasibility of Cage Culture in the Coastal waters adjacent to St. Martin's Island

The selection of areas for cultivating herbivore, carnivore, and omnivore fish was based on the abundance and distribution of physicochemical properties, nutrients, heavy metals, and plankton in the vicinity of stations 10, 9, and 8, respectively. However, the scope of this study was limited to the cultivation of carnivorous species, serving as an initial effort to evaluate the economic feasibility of cage farming in response to their significant market demand. According to the data that was gathered, it was found that the initial phase of the pre-monsoon hot season, specifically during the months of March and April, exhibited greater suitability for the purpose of stocking fingerling within the cage. Nevertheless, for the purposes of this study, the period between January and May, which encompasses the transition from the chilly dry winter season to the pre-monsoon hot season, was selected for cage cultivation due to the fulfilment of all requisite circumstances throughout this timeframe.

The selection of suitable fish species for cultivation in the coastal waters adjacent to the Island was based on various criteria, including the availability of plankton and supplementary food, the compatibility with seawater's physicochemical properties, nutrient content, heavy metal levels, and other important factors. Among the chosen species were the Milk fish (*Chanos Chanos*), a planktivorous fish, the John's Snapper/ John's Sea Perch (*Lutjanus johnii*) and Asian Sea Bass (*Lates calcarifer*), both carnivorous fishes, and the Flathead Grey Mullet (*Mugil cephalus*), an omnivorous fish. The present study focused on the evaluation of the economic feasibility of cage farming by cultivating John's Snapper (*Lutjanus johnii*) as the selected species.

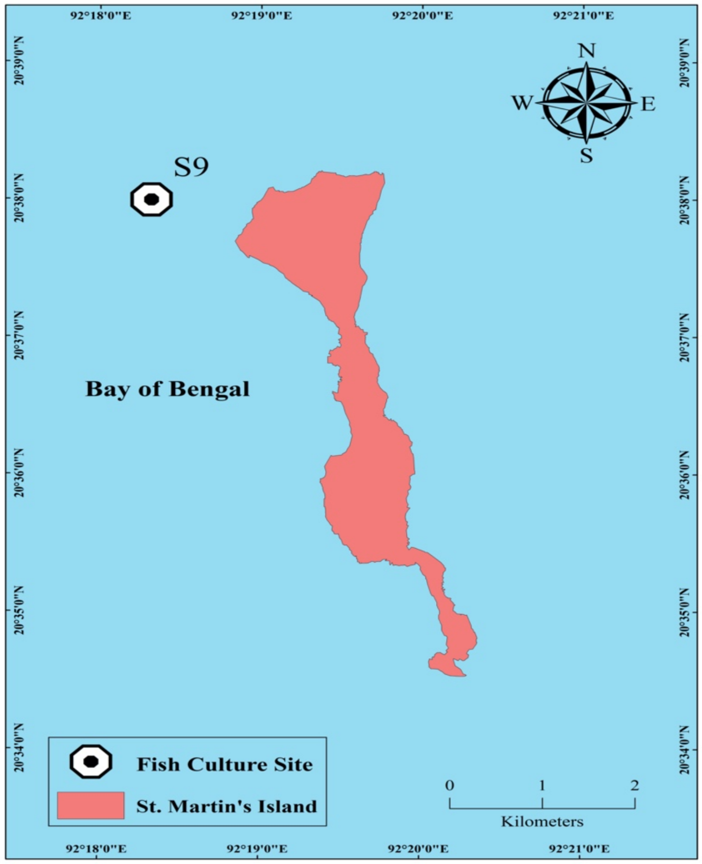


Figure 6.71 Selected site for cage installation to cultivate John's Snapper/ John's Sea Perch (*Lutjanus johnii)*

6.5.1 Cost of Cage Construction

Cages can be stationary, floating, submersible, or submerged. The most basic and popular cage is the fixed cage, which is utilized in water that is 1to 3 meters deep. In this study fixed cage was used for cultivation of the selected species. Cost of cage depend on its size and scale of culture. For a big scale commercial cage culture, the construction of cage cost will be much higher than a regular cage made by the local people for cage culture. In this study, one small scale cage was constructed to check the feasibility of cage culture by the local unemployed people to improve their livelihood.

The cost is also depended on the availability of raw materials required for the construction of the cage. In this study, three cages were constructed with materials-iron frame (40 kg), empty plastic drams as floats (4 nos), anchors (2 nos), and nylon net ($70ft^2$) etc for each collected from the local market of Cox's bazar. The fixed cost of each cage including construction materials (3200 Tk), welding (1000 Tk), sewing (600 Tk), anchor (1700 Tk), float (1600 Tk), transport (500 Tk), labor (600 Tk), installation and others (300 Tk) was 10,060 Tk.

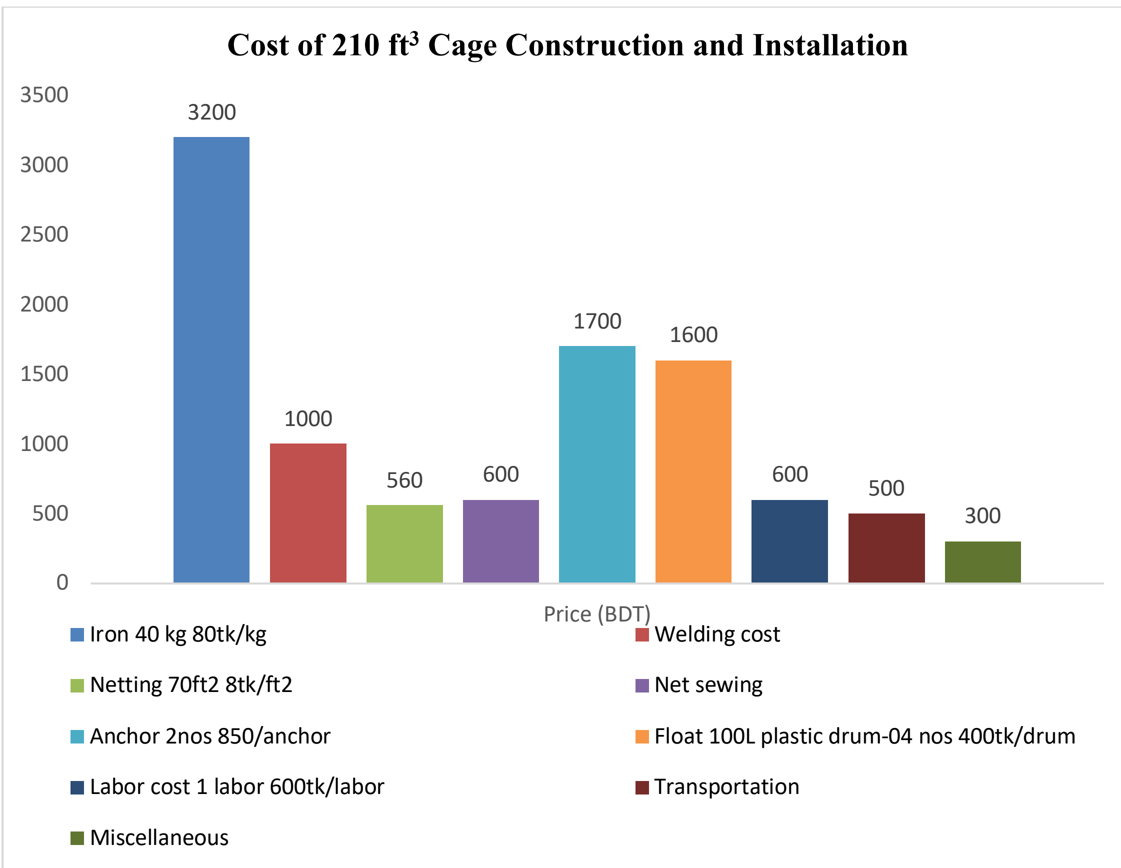


Figure 6.72 Fixed cost of cage construction and installation for farming John's Snapper (Lutjanus johnii)

Item wise fixed cost in Percentage (%): Iron (17.24%), net (3.01%), welding (5.38%), sewing (3.23%), anchor (9.15%), float (8.62%), transport (2.69%), labor (3.23%) and miscellaneous (1.61%).

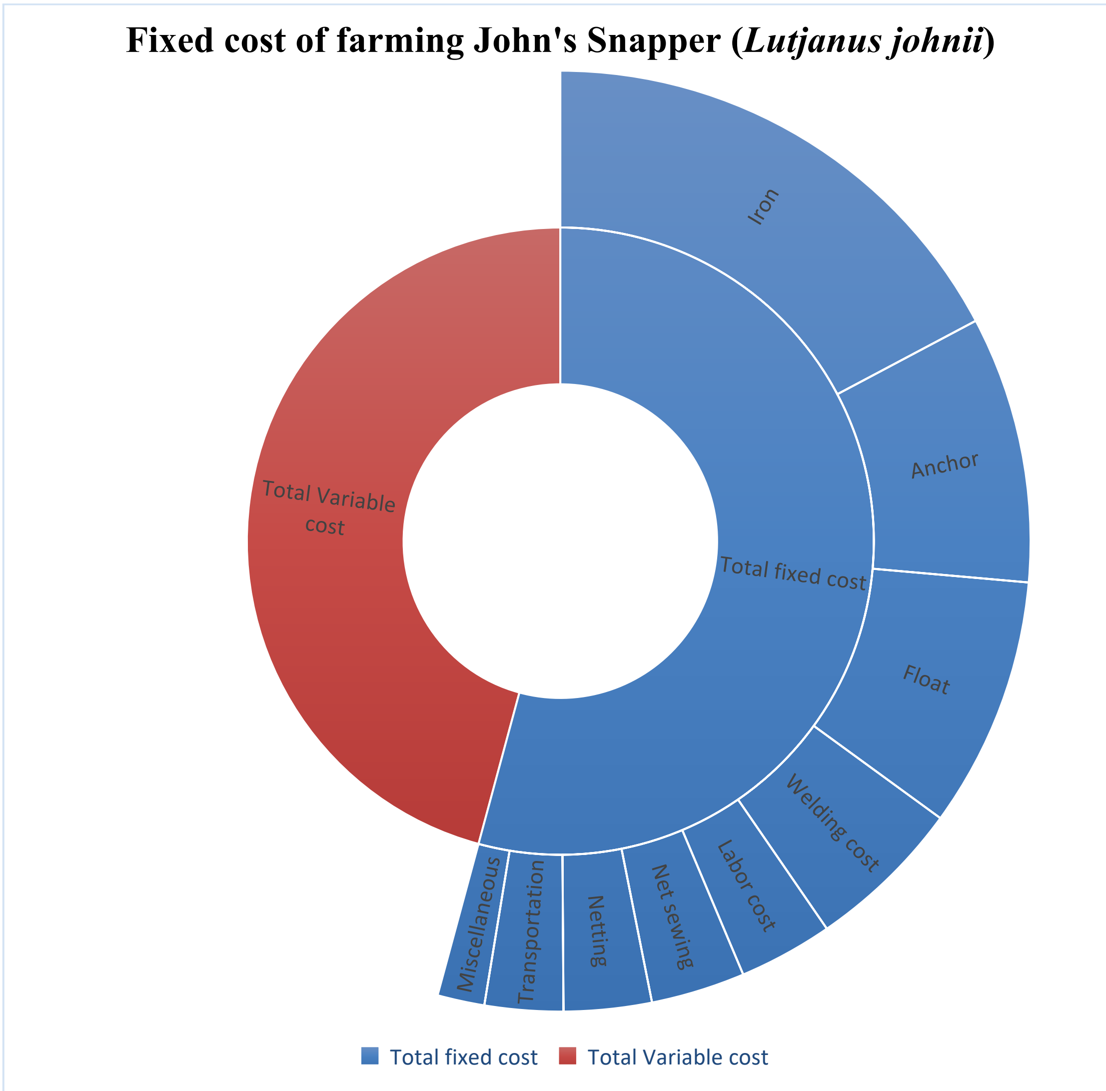


Figure 6.73 Item wise Fixed Cost of 210 ft³ Cage Construction and Installation (in percentage) for farming John's Snapper (Lutjanus johnii)

Item wise variable cost in Percentage: Variable cost includes fingerlings (8.08%), supplementary feed (18.85%), labor (10.77%) and miscellaneous (8.08%).

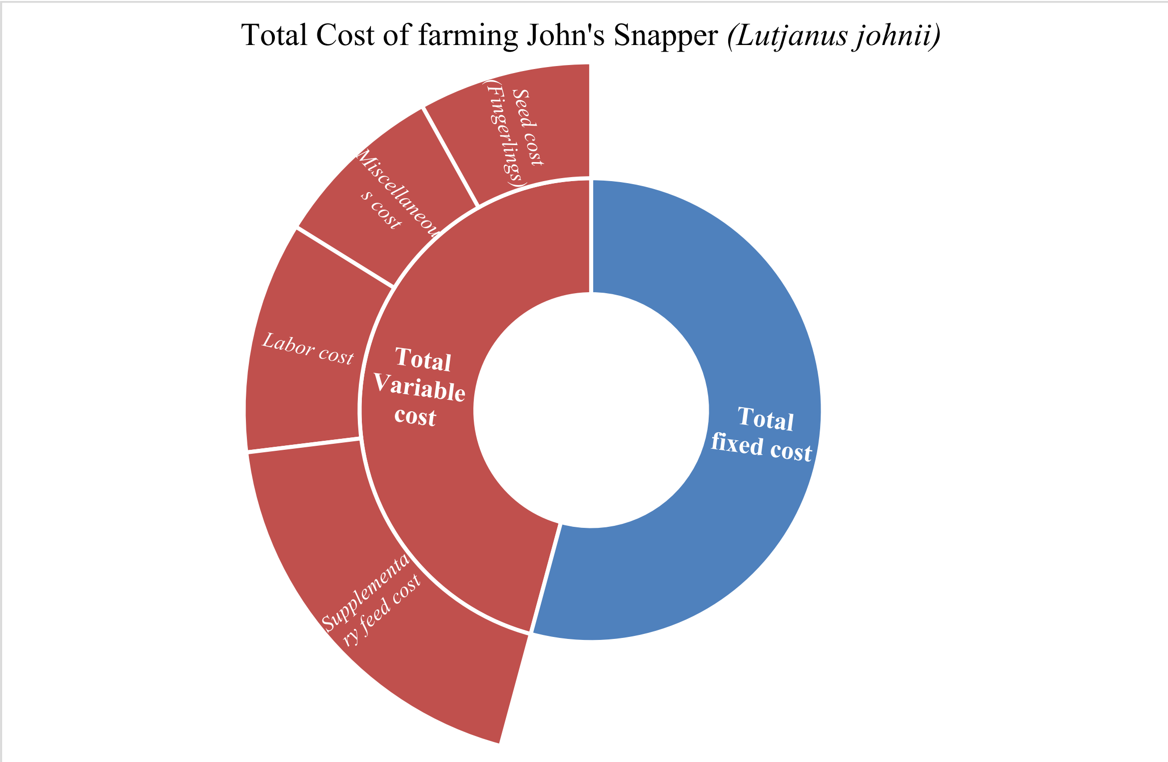


Figure 6.74 Item wise variable Cost (in percentage) to cultivate John's Snapper (Lutjanus johnii) in a 210 ft³ Cage

6.5.2 Feasibility of Farming John's Snapper (*Lutjanus johnii*) in Cage in the Coastal waters adjacent to St. Martin's Island

At every stage of production, cost is an important factor that helps farmers make the best decisions. This study focuses on the fixed costs and other costs associated with fish production and the final output of farmed fish, as well as the benefit cost ratio (BCR). Most inputs were priced at their current market price in the study region during the study period (January to May 2022). Jhon's Snapper's (*Lutjanus johnii*) economic viability was determined by calculating its total cost mortality rate, survival rate, net production, gross return, gross margin, net return, and benefit cost ratio.

6.5.2.a Cost of Cultivation

Total Cost (TC)= Fixed Cost+ Variable Cost

= (10060+8500) BDT

= 18,560 BDT

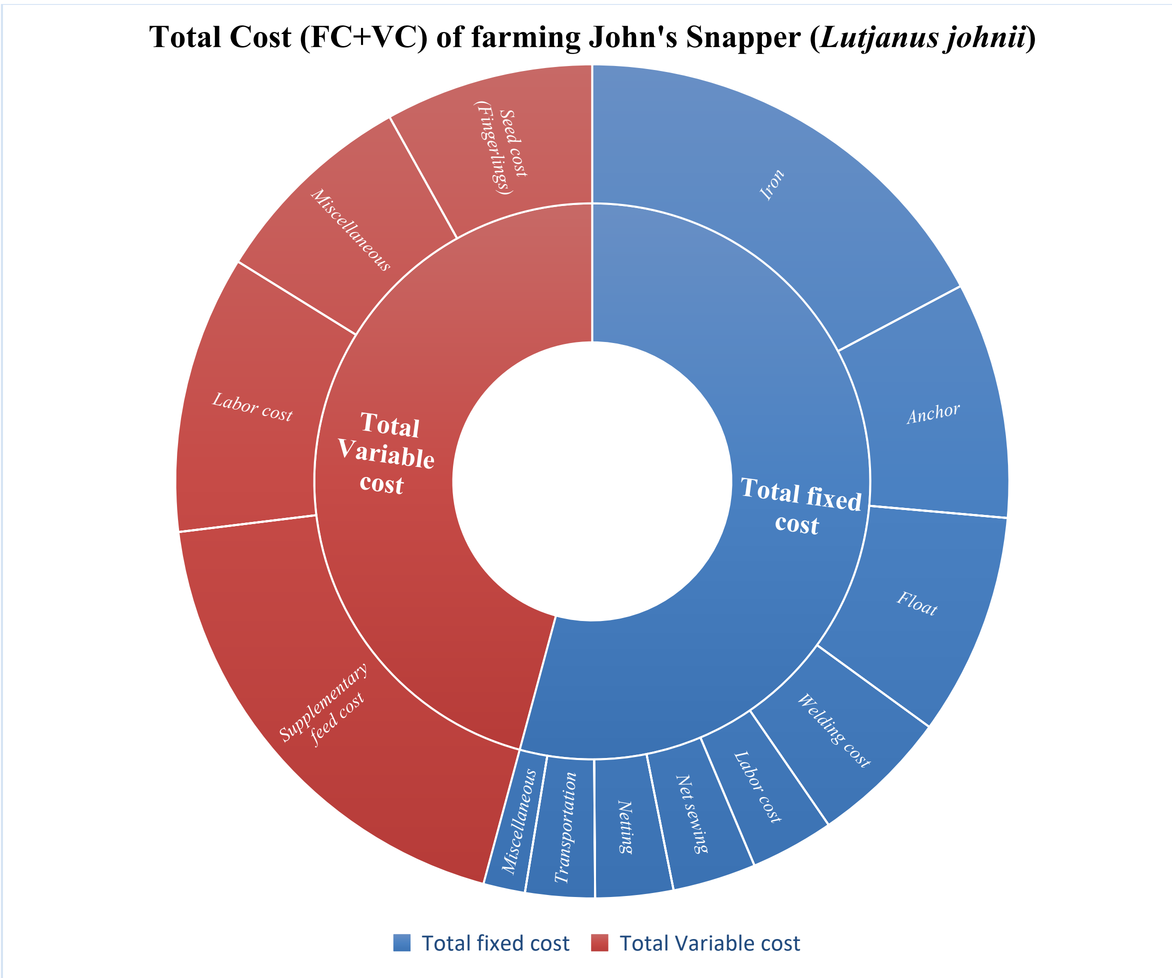


Figure 6.75 Item wise Total Cost (TC+VC) of farming John's Snapper (Lutjanus johnii) in percentage in the coastal waters adjacent to St. Martin's Island

The fixed cost of each cage encompasses expenses related to building supplies, welding, sewing, installation, shipping, and labor, amounting to a sum of 10,060 Tk in total and variable cost includes fingerlings (1500 Tk), supplementary feed (3500 Tk), labor (2000 Tk) and miscellaneous (1500 Tk).

6.5.2.b Length Calculation

Von Bertalanffy equation, in terms of length, is:

$$\mathbf{L_t = L_\infty - (L_\infty - L_0)\, e^{-k\,t}}$$

Here, Asymptotic length of John's Snapper

$L_\infty = 100$cm

Average length of an individual at time to,

$L_0 = 10.33$ cm

Average length of an individual after 5 months of cultivation,

$L_5 = 27.41$cm

Using the Von Bertalanffy Equation in terms of length, the growth coefficient (K) was calculated:

$$K = -\frac{1}{5} \times \ln \frac{L_\infty - L_5}{L_\infty - L_0}$$

$$= -\frac{1}{5} \times ln \frac{100-27.41}{100-10.33}$$

= **0.0423**

Applying the Von Bertalanffy Equation in terms of length, average estimated length of an individual after 6 months of cultivation,

$$L_t = L_\infty - [L_\infty - L_0]\, e^{-k\,t}$$

$$= 100-[100- 10.33]\, e^{-0.0423\times 6}$$

= 30.43 cm

Table 6.20 Length and weight relationship and their logarithmic value of randomly selected 10 Snapper after 5 months of cultivation

L(cm)	W(g)	X=log(L)	Y=log(w)	XY	X^2	Y^2
28.50	373.59	1.4548	2.5724	3.7424	2.1166	6.6172
27.28	326.78	1.4358	2.5143	3.6101	2.0616	6.3215
27.32	328.25	1.4365	2.5162	3.6145	2.0635	6.3313
26.57	301.45	1.4244	2.4792	3.5314	2.0289	6.1465
28.15	359.73	1.4495	2.5560	3.7048	2.1010	6.5330
26.70	305.98	1.4265	2.4857	3.5459	2.0349	6.1787
27.65	340.53	1.4417	2.5322	3.6506	2.0785	6.4118
26.50	299.02	1.4232	2.4757	3.5235	2.0256	6.1291
27.64	340.16	1.4415	2.5317	3.6495	2.0780	6.4096
27.80	346.22	1.4440	2.5394	3.6669	2.0853	6.4483
		$\sum x$ **=14.3779**	$\sum y$ **=25.2028**	$\sum xy$ **=36.2395**	$\sum x^2$ **= 20.6734**	$\sum y^2$ **= 63.5277**

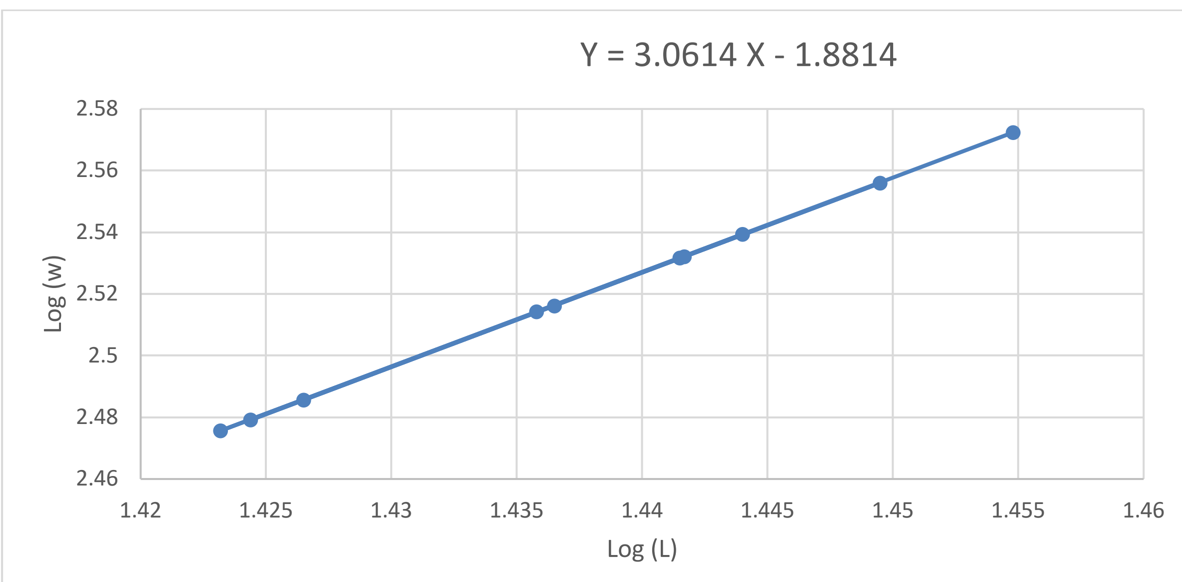


Figure 6.76 ***Correlation between logarithmic value of weight and length of John's Snapper (Lutjanus johnii)***

6.5.2.c Weight Calculation

$$b = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2}$$

$$= \frac{10\times 36.2395 - 14.3779\times 25.2028}{10\times 20.6734 - (14.3779)^2}$$

$$= 3.0614$$

$$a' = \frac{\sum y - b\sum x}{n}$$

$$= \frac{25.2028 - 3.0614\times 14.3779}{10}$$

$$= -1.8814$$

$$a = 10^{-1.8814}$$

$$\mathbf{= 0.0131}$$

Applying the Equation of Length-Weight Relationship, Mean estimated weight of an individual after 6 months of cultivation,

$$W = a\,L^{b}$$

$$= 0.0131\times (30.43)^{3.0614} = \mathbf{455.25\ g}$$

6.5.2.d Mortality and Survival Rate

Initial population number, N_0=140

Number of individuals after 5months,

N_5 = 102

Using Exponential Decay Equation,

$N_5 = N_0 e^{-z\times 5}$

Or, $102 = 140\times e^{-z\times 5}$

Or, z = 0.0633/month

Where,

Z = Instantaneous rate of total mortality

Survival Rate (%) = $100 \times e^{-0.0633}$

= 93.87% /month

Mortality Rate (%) = $100 \times (1-e^{-0.0633})$ = 6.13% /month

Applying the Exponential Decay Equation, the estimated number of individuals after 6 months of cultivation would be-

$$N_t = N_0 \times e^{-zt}$$

$$= 140 \times e^{-0.0633 \times 6}$$

$$= 95$$

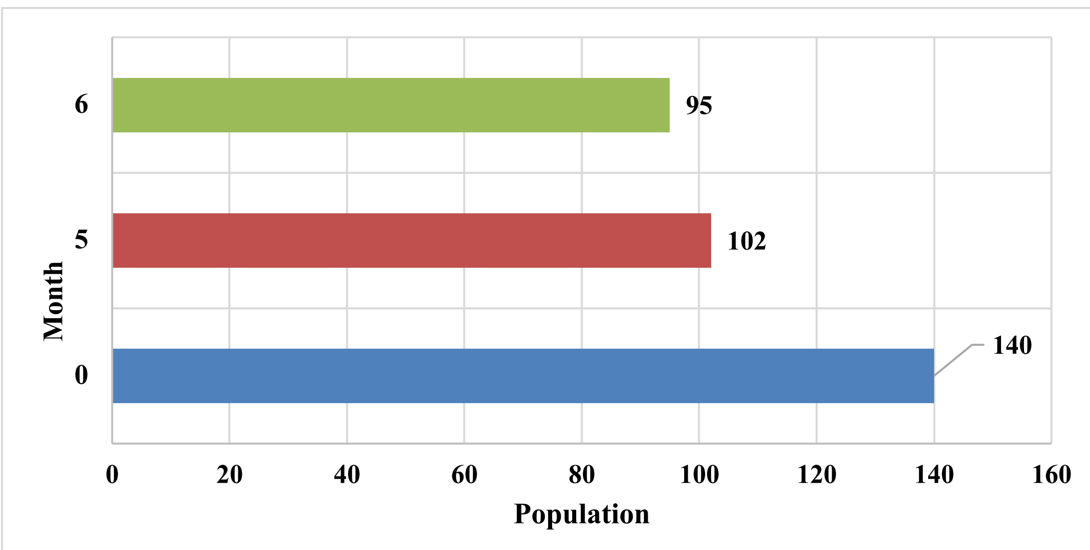


Fig 6.77 Time series analysis of the fluctuating John's Snapper population size

6.5.2.e Total Production:

Total production was calculated by multiplying average weight of an individual by the number of individuals:

Here,

Average weight of an individual= 455.25 g

Number of individuals=95

Total production =455.25× 95 g

= 43248.75 g

=43.25 kg

The entirety of the substantial can be comprehended- Average initial length 10.33 cm, Average initial weight 16.72 gm, Number of individuals stocked in cage initially 180, Instantaneous rate of total mortality 0.0633/month, Survival Rate 93.87%, Mortality Rate 6.13%, Number of total living individual after 5 months of cultivation 102, Estimated number of total living individual after 6 months of cultivation 95, Average weight of each individual after 6 months of cultivation 455.25 gm and Total Production 43.25 kg.

6.5.2.f Gross Return

The gross return is the whole monetary value of the product. To calculate gross returns, the whole volume of production was multiplied by the relevant market prices. Here,

Total production= 43.25 kg

Prices of fish (BDT/kg) =500 BDT

Gross return = 43.25×500

=21,625 BDT

6.5.2.g Net Return

The income of an entrepreneur is usually called their "net return." When figuring out how profitable fish aquaculture is, the net return is one of the most important things to look at. The net return is calculated by subtracting the gross profit from the total expenses.

Here,

Gross return =21,625 BDT

Total costs = 18,560 BDT

Net return =Gross return - Total costs

= 21625 – 18560

= 3065 BDT

6.5.2.h Gross Margin:

The relative profitability of fish firming has been determined using the gross margin analysis. The difference between gross return and all variable costs is known as gross margin.

Here,

Gross return = 21625 BDT

Total variable costs= 8500 BDT

Gross margin = 21625-8500 BDT

= 13,125 BDT

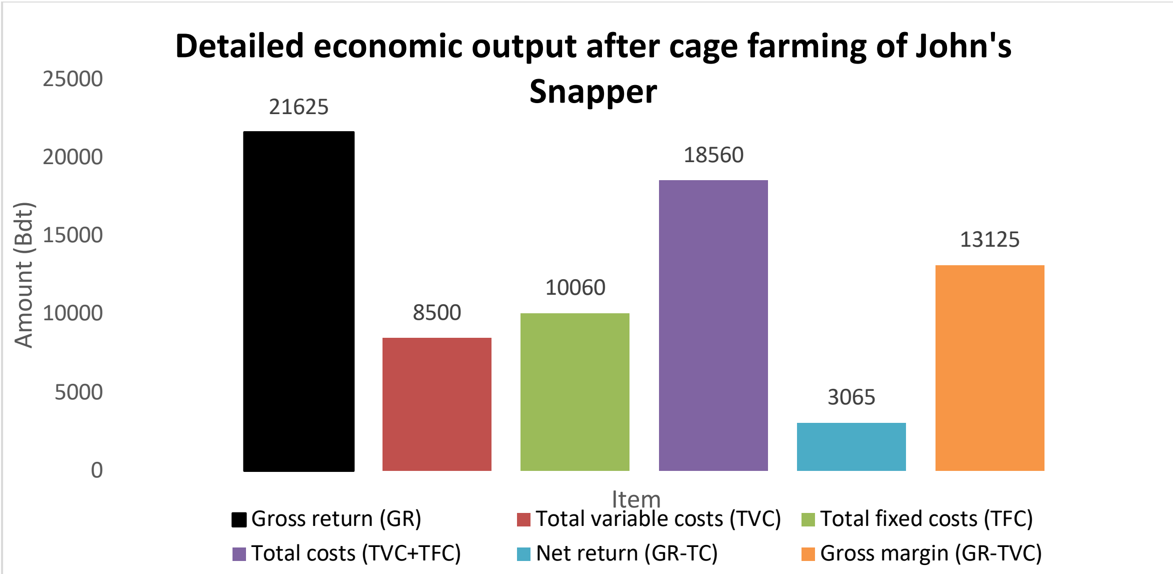


Figure 6.78 Economic output after cage farming of John's Snapper (Lutjanus johnii) in the coastal waters adjacent to St. Martin's Island.

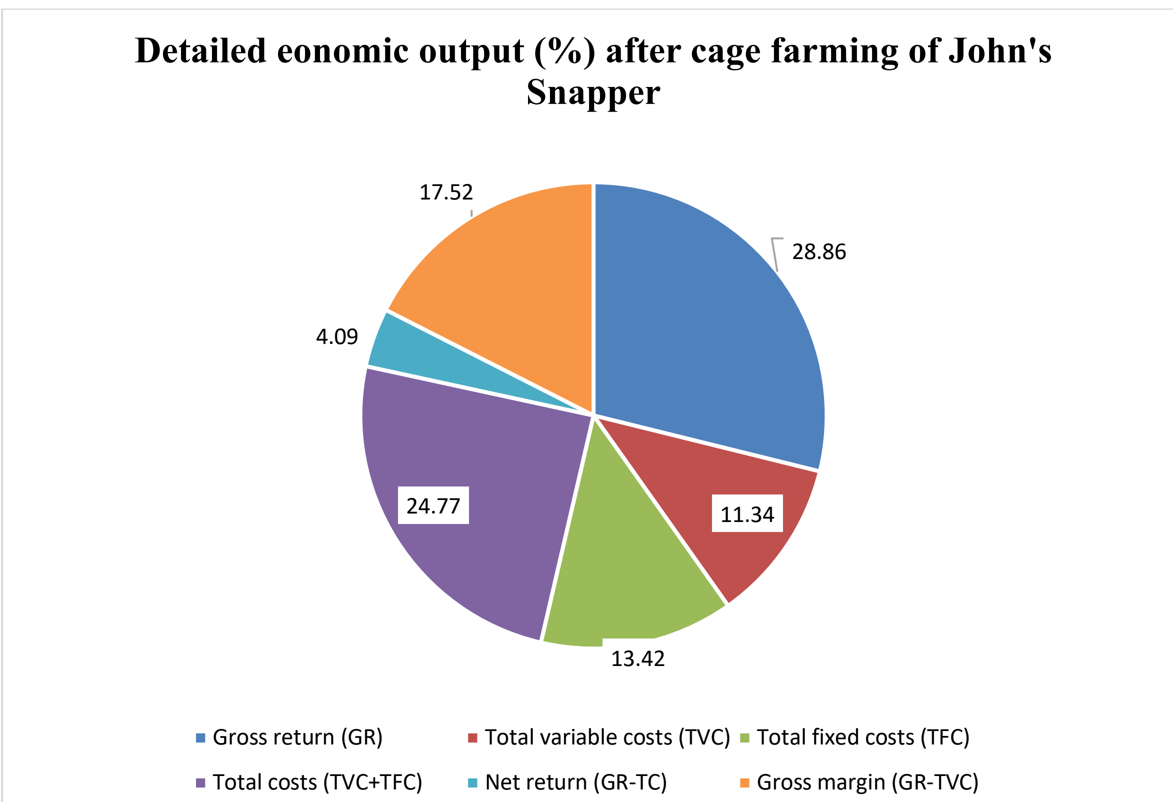


Figure 6.79 Economic output in percentage after cage farming of John's Snapper (Lutjanus johnii) in the coastal waters adjacent to St. Martin's Island.

6.5.2.i Benefit Cost Ratio (BCR)

By dividing gross return by total costs, the benefit cost ratio (BCR) was calculated.

Here,

Gross return (GR) =21625TK

Total costs (TC) =18560 TK

$$BCR = \frac{GR}{TC}$$

$$= \frac{21625}{18560}$$

$$\mathbf{=1.1651}$$

BCR>1 indicates that farming of **John's Snapper** ***(Lutjanus johnii)*** is **economically feasible** in the coastal water adjacent to St. Martin's Island.

Remarks: This study reveals that **John's Snapper/Sea Perch** ***(Lutjanus johnii)*** farming at Saint Martin's Island is profitable. As this omnivorous fish requires supplementary feed after its juvenile period for cultivation, involving local unemployed communities in the cultivation of this species in a cage could be costly for them, whereas the cultivation of this species on a larger scale by any fish farm with supplementary feed could be extremely lucrative. This study demonstrates that cage culture of John's Snapper (*Lutjanus johnii*) on a small scale on St. Martin's Island in Bangladesh by the local community was economically profitable but the study suggest that cultivation of herbivorous fish involving local unemployed communities could be more feasible than carnivorous and omnivorous fishes as cultivating carnivorous and omnivorous fishes need supplementary feed at least twice a day, but cultivation of those fishes could be very profitable for any fish farm on a large scale with the right equipment and enough supplementary feed. It could be said that large scale cage culture farm may can create numerous jobs to Island dwellers.

6.6 Feasibility of Seaweed Culture in the Coastal waters adjacent to St. Martin's Island

Environmental parameters such as depth, current, shelter, wind, wave, seabed, and water quality are the most essential elements for selecting a site for cage culture. It was elaborately discussed in chapter 4. Based on the distribution of physicochemical properties, nutrients, and heavy metals, the region adjacent to sampling station 1 was identified as the most appropriate location. However, it is worth noting that stations 10 and 12 also exhibit characteristics that render them potentially suitable alternatives. The suitable parameters indicated that Seaweed could be cultivated from October to April in the coastal water adjacent to St. Martin Island. In this particular study, the cool dry winter season (January 2022) was chosen to implant the seaweeds for growing because all of the desirable attributes required for seaweed culture were observed during that time; however, Pre monsoon hot season might also be considered for seaweed culture.

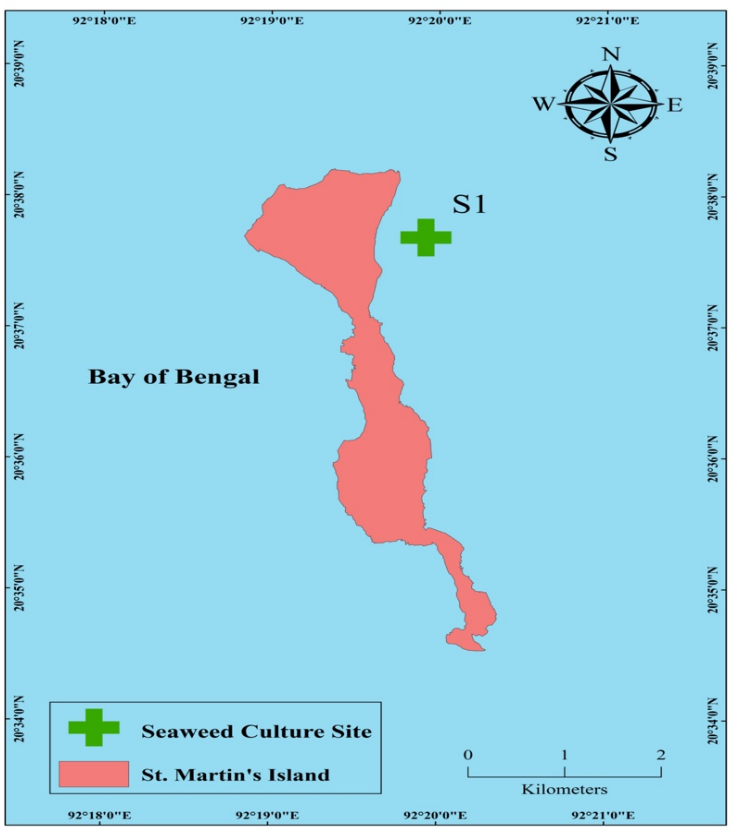


Figure 6.80 Selected site for cultivation of seaweed from both aspect of sampling

Based on an assessment of the physicochemical properties of the water, nutrient distribution, heavy metal distribution, commercial importance, and availability, the species *Ulva intestinalis* (Green algae), *Gracilaria gracilis* (Red algae), and *Padina gymnospora* (Brown algae) were identified as the most appropriate species for cultivation in the coastal water proximate to St. Martin's Island. The present study focused on the cultivation of *Padina gymnospora* as a representative species for evaluating the economic feasibility of seaweed agriculture on the island. Both the long line and floating net methods were used in this investigation.

6.6.1 Total Weight of Seaweed using Long Line Method (LLM)

6.6.1.a Daily Growth Rate (Weight)

Daily Growth Rate (Weight) was calculated for Long Line Method by the formula of Juanich, (1988).

DGR (weight) = $\frac{TW-OW}{No.\ of\ Culture\ Days}$

Where, TW= Total weight of plant after harvesting

OW= Original weight of the plant before test planting

No. of culture days = Period of test planting

***Padina gymnospora* (Brown Algae)**

The value of TW_{Padina} = 2.5 kg per line

Number of lines used for cultivation = 6

So, TW_{Padina} = 6 × 2.5 kg = 15 kg = 15000 gm

OW_{Padina} = 350 gm per line

As the number of line was 6 for ***Padina gymnospora*** cultivation

The value of $OW_{Padina} = 350 \times 6 = 2100$ gm (seedlings)

After cultivation of 30 days period, the value of **DGR(weight)** = $\frac{15000-2100}{30}$ gm/day

= **430 gm/day**

From the calculation, the Daily Growth Rate (weight) of ***Padina gymnospora*** **(Brown Algae**) after cultivation of 30 days using Long Line Method was about **430 gm/day.**

Table 6.21 Daily Growth Rate (Weight) of the cultivated *Padina gymnospora* during Cool dry winter Season using Long Line Method.

Species	**Amount of line**	**OW (gm Per Line)**	**OW (Total gm)**	**TW (gm)**	**No. of culture days**	**Daily Growth Rate** (weight) (gm/day)
***Padina gymnospora* (Brown Algae)**	6	350	2100	15000	30	**430**

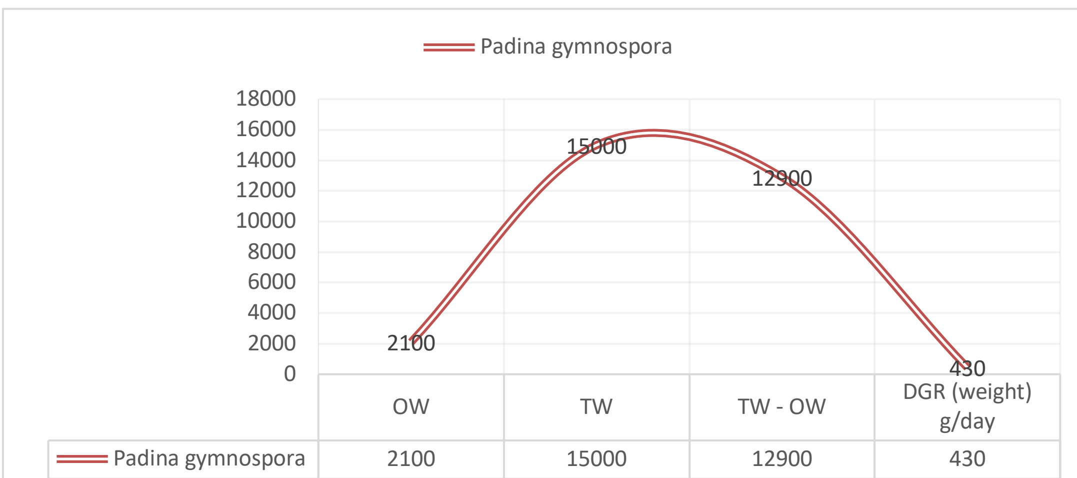


Figure 6.81 Daily growth rate (weight) of the cultivated *Padina gymnospora* using Long Line Method during Cool dry winter Season

6.6.1.b Daily Growth Rate (Weight) in Percentage

Daily Growth Rate (Weight) in Percentage for Long line Method was calculated by the formula of Hung et al., (2009).

DGR (%) = $[(W_t / W_o)^{1/t} - 1] \times 100$ %/day

Where: W_0 = Initial fresh weight (seedlings weight)

Wt = Final fresh weight (Cultured seaweed weight)

and t = Days of culture

***Padina gymnospora* (Brown Algae)**

W_0 = 2100 gm (Total in 6 lines)

W_t = 15000 gm

T = 30 days.

DGR_{Padina} = **$[(15000/2100)^{1/30} - 1] \times 100$ % /day**

= **6.773 % /day**

6.6.2 Total Weight of Seaweed using Floating Net Method (FNM)

6.6.2.a Daily Growth Rate (Weight)

Daily Growth Rate (Weight) was calculated for Floating Net Method by the formula of Juanich, (1988).

DGR (Weight) $= \dfrac{TW - OW}{\text{Number of culture days}}$

Where, TW= Total weight of plant after test planting

OW= Original weight of the plant before test planting

No. of culture days = Period of test planting

***Padina gymnospora* (Brown Algae)**

TW_{Padina} = 20000 gm

OW_{Padina} = 3000 gm (seedlings)

Number of culture days = 30

After cultivation of 30 days period, the value of **DGR(weight)** $= \dfrac{20000 - 3000}{30}$ **gm/day**

= 566.67 gm/day

From the calculation, the Daily Growth Rate (weight) of ***Padina gymnospora* (Brown Algae)** after cultivation of 30 days using Floating Net method was about **566.67 gm/day.**

Table 6.22 Daily Growth Rate (weight) of the cultivated *Padina gymnospora* during Cool dry winter Season using Floating Net Method.

Species	TW (gm)	OW (gm)	No. of Culture Days	Daily Growth Rate (weight) (gm/day)
***Padina gymnospora* (Brown Algae)**	20000	3000	30	**566.67**

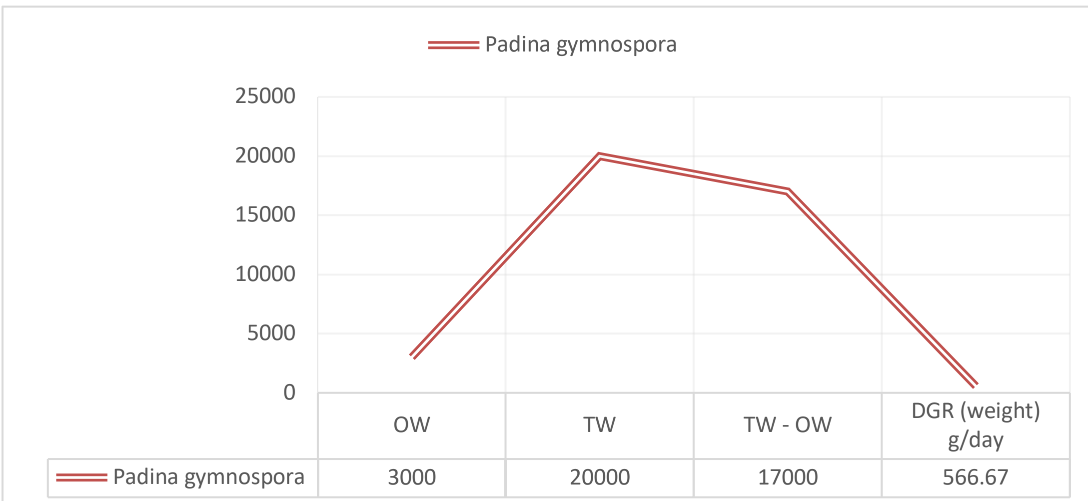


Fig 6.82 Daily growth rate (weight) of the cultivated *Padina gymnospora* during Cool dry winter Season using Floating Net Method.

6.6.2.b Daily Growth Rate (Weight) in Percentage

Daily Growth Rate (weight) in Percentage for Floating Net Method was calculated by the formula of Hung et al., (2009).

DGR (%)= $[(Wt / Wo)^{1/t} - 1] \times 100$ %/day

Where: W_0 = Seedlings weight

W_t = Cultured seaweed weight

and t = days of culture

***Padina gymnospora* (Brown Algae)**

W_0 = 3000 gm

W_t = 20000 gm

T = 30 days

DGR_{Padina} = [(20000/3000) $^{1/30}$-1] ×100 % /day

= 6.528 % /day

6.6.3 Total Growth (Length) of Seaweed using Long Line Method (LLM)

6.6.3.a Daily Growth Rate (length) in Percentage

Daily Growth Rate (length) in Percentage was determined by the formula of Yong et al., (2013).

$DGR_{Length} = [(L_t/L_0)^{1/t} – 1] \times 100\%$

Where, L_t = Cultured seaweed length

L_0 = Seaweed seedlings length

t = no. of culture days

Table 6.23 Seedlings length and cultivated seaweed length in Long Line Method.

Seaweed Species	L_0 (Seaweed seedlings length) (cm)	L_t (Cultured seaweed length) (cm)
***Padina gymnospora* (Brown Algae)**	2.7	12

***Padina gymnospora* (Brown Algae)**

L_t = 12 cm

L_0 = 2.7 cm

And t = 30 days.

Now, **$DGR_{Padina} = [(12/2.7)^{1/30}-1] \times 100$ % /day**

= 5.098 % /day

From the calculation, the Daily Growth Rate (length) in percentage of for ***Padina gymnospora*** was **5.098 % /day** after cultivation of 30 days using Long Line Method**.**

6.6.4 Total Growth (Length) of Seaweed using Floating Net Method (FNM)

6.6.4 a Daily Growth Rate (length) in Percentage

Daily Growth Rate (length) in percentage was determined by the formula of Yong et al., (2013).

$DGR_{Length} = [(Lt/L0)^{1/t} – 1] \times 100\%$

Where, Lt = Cultured seaweed length

L0 = Seaweed seedlings length

t = No. of culture days.

Table 6.24 Seedlings length and Cultivated seaweed length in Floating Net Method.

Seaweed Species	L_0 (Seaweed seedlings length) (cm)	L_t (Cultured seaweed length) (cm)
Padina gymnospora **(Brown Algae)**	2.7	10

Padina gymnospora **(Brown Algae)**

Lt = 10 cm

L_0 = 2.7 cm

And t = 30 days.

Now, **$DGR_{Padina} = [(10/2.7)^{1/30}-1] \times 100$ % /day**

= 4.461 % /day

From the calculation, the Daily Growth Rate (length) in percentage of ***Padina gymnospora*** was **4.461 % /day** after cultivation of 30 days using Floating Net Method**.**

6.6.5 Total Biomass Production of Seaweed using Long Line Method (LLM)

6.6.5.a Total Biomass Production

Total Seaweed biomass production can be calculated by the formula given by Doty et al., (1987).

$Y = (W_t - W_o) / A$

Here,

Y = Net production of biomass of all seaweeds in long line method.

W_t = Fresh weight of seaweeds after **30 days** cultivation.

W_0 = Fresh weight of seaweed seedlings.

A = Area of long line culture site,

Now, for long line method

W_t = 15000 g

W_0 = 2100 g

= 15000-2100 g

= 12900 g

A = $(40 \times 12)\ ft^2$

= $(12.192 \times 3.657)\ m^2$

= $44.586\ m^2$

Total Biomass Production, $Y_{LLM} = \frac{15000 - 2100}{44.586}$

= **$289.328\ g/m^2$**

So, net production of biomass of cultivated ***Padina gymnospora*** in Long Line Method was **289.328 g/m^2**

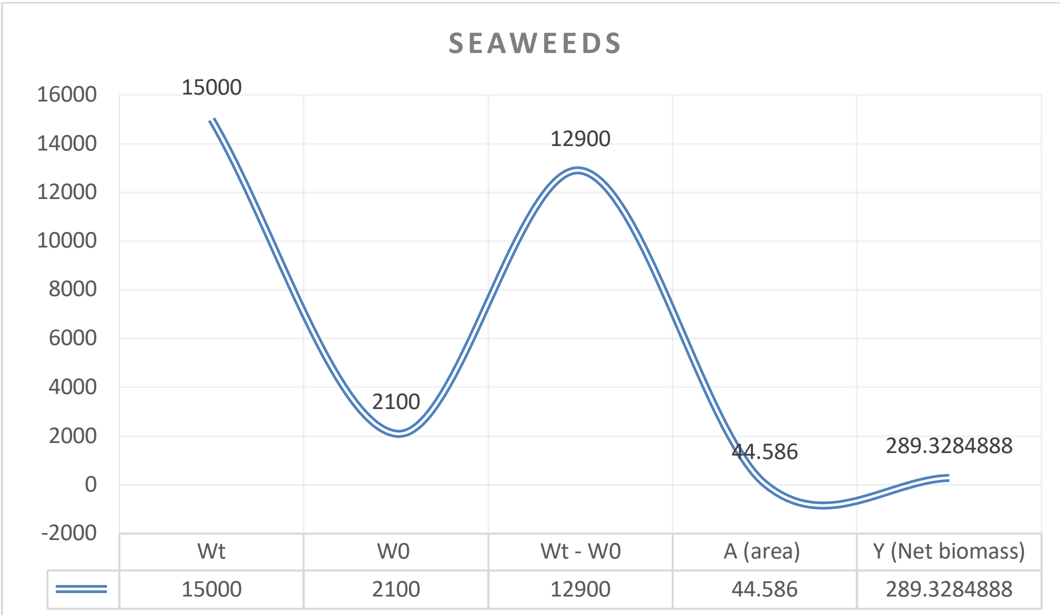


Figure 6.83 Net production of Biomass of Padina gymnospora seaweeds in long line method.

6.6.6 Total Biomass Production of Seaweed from Floating Net Method (FNM)

Seaweed biomass production can be calculated by the formula given by Doty et al., (1987)

$$\mathbf{Y = (W_t - W_o) / A}$$

Here, Y = Net production of biomass of seaweeds in floating net method.

W_t = Fresh weight of seaweeds after **30 days** cultivation.

W_0 = Fresh weight of seaweed seedlings in floating net method.

A = area of net culture site,

Now, for floating net method,

W_t = 20000g

W_0 = 3000 g

A = (40 × 12) ft^2

= (12.192 ×3.657) m^2

= 44.586 m^2

Total Biomass Production, $Y_{FNM} = \dfrac{20000 - 3000}{44.586}$

$= 381.285\ g/m^2$

So, net production of biomass of cultivated three seaweeds in floating net method was **381.285 g/m^2.**

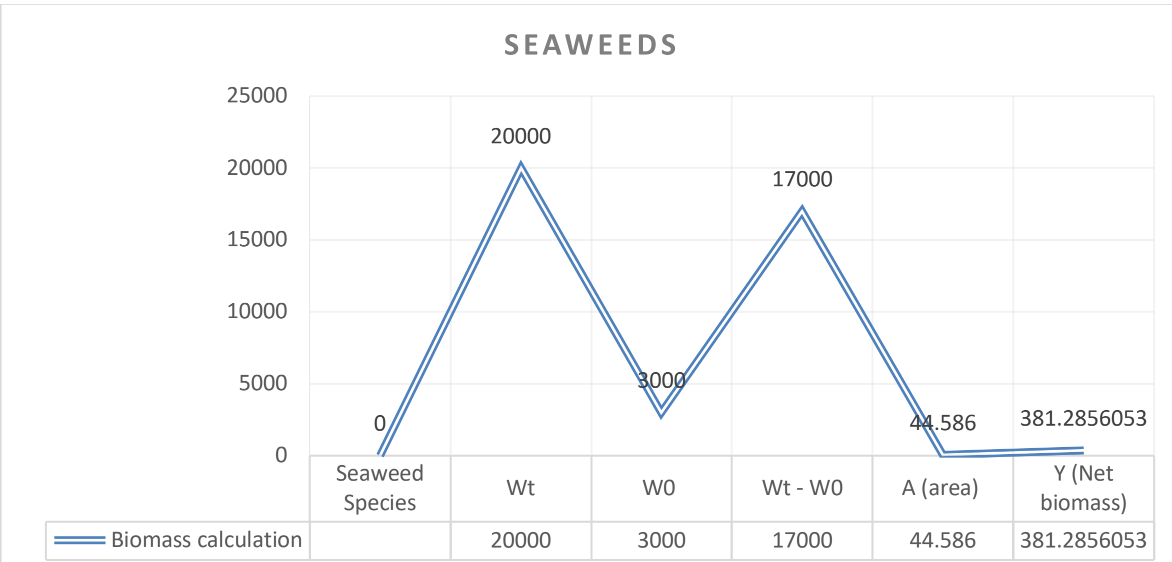


Figure 6.84 Net production of Biomass of cultivated three seaweeds using Floating Net method.

6.6.7 Benefit Cost Ratio (BCR) of Seaweed Culture

Cost Benefit Ratio (CBR) could be calculated by using the following formula,

$$\mathbf{BCR} = \frac{GR}{TC}$$

Where, **GR = Gross Return**

TC = Total Cost

BCR = Cost-Benefit Ratio

If the value of **BCR > 1** means the cultivation of the species is **profitable.**

If the value of **BCR < 1** means the cultivation of the species is **not profitable.**

If the value of **BCR =1** which indicates the **Break-Even Point (BEP).**

6.6.7.a Benefit Cost Ratio of Seaweed Culture using Long Line Method

***Padina gymnospora* (Brown Algae)**

Table 6.25 Total Cost (TC) for preparing the *Padina gymnospora* culture site using Long Line Method (LLM)

Item	Cost (BDT)
Bamboo Pole	500
Nylon Rope	350
Bobbin Thread	50
Others	150
Total Cost (TC)	**1050 BDT**

Total Production = 15000 gm = 15 kg

Per unit price (kg/unit) = **180 Taka**

Gross Return (GR) = 15×180 = 2700 Taka

Benefit Cost Ratio (BCR) = $\frac{GR}{TC}$

$$= \frac{2700}{1050} = 2.571$$

BCR > 1 indicates that ***Padina gymnospora* (Brown Algae)** cultivation using Long Line Method is **profitable.** Here, **BCR=2.571** means it is very profitable to grow this seaweed on a small or large scale in the coastal waters near St. Martin's Island.

6.6.7.b Benefit Cost Ratio of Seaweed Culture using Floating Net Method

***Padina gymnospora* (Brown Algae)**

Table 6.26 Total Cost (TC) for preparing the *Padina gymnospora* culture site using Floating Net Method (FNM)

Item	Cost (BDT)
Bamboo Pole	500
Lakkha Fish Net	500
Bobbin Thread	20
Nylon Rope	30
Others	50
Total Cost (TC)	**1100 BDT**

Total Production = 20000 gm = 20 kg

Per unit price (kg/unit) = **180 Taka**

Gross Return (GR) = 20×180 = 3600 Taka

Benefit Cost Ratio (BCR) = $\frac{GR}{TC}$

$$= \frac{3600}{1100} = 3.272$$

BCR > 1 indicates that ***Padina gymnospora*** **(Brown Algae)** cultivation using Floating Net Method (FNM) is **profitable.** Here, **BCR= 3.272** means it is quite profitable if this seaweed cultivated on a small or large scale in the coastal waters adjacent to St. Martin's Island.

6.6.8 Comparison of Daily Growth Rate (weight) per Day for LLM and FNM

In the case of the long line approach, the growth rate (weight) per day for *Padina gymnospora* (Brown Algae) was 430 grams per day. In contrast, the growth rate (weight) per day for *Padina gymnospora* (Brown Algae) using the floating net method was 566.67 grams per day.

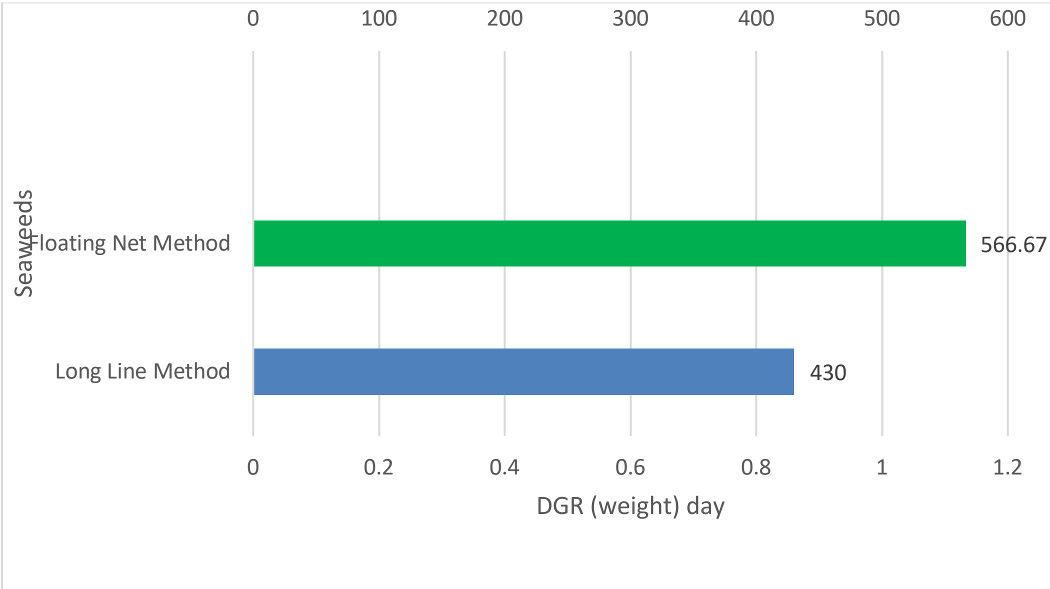


Figure 6.85 Comparison of Daily Growth Rate (Weight) of Padina gymnospora per day among long line and floating net method

6.6.9 Comparison of Daily Growth Rate (weight/length) in Percentage per Day for LLM and FNM

For long line method, the growth rate (weight) per day in percentage was about **6.773 %,/day o**n the Other hand, for floating net method **6.528 %**/day for *Padina gymnospora* (Brown Algae). For long line method, the growth rate (length) per day in percentage was **5.098 %/day,** On the other hand, for floating net method, the values was **4.461 %/day** for *Padina gymnospora* (Brown Algae).

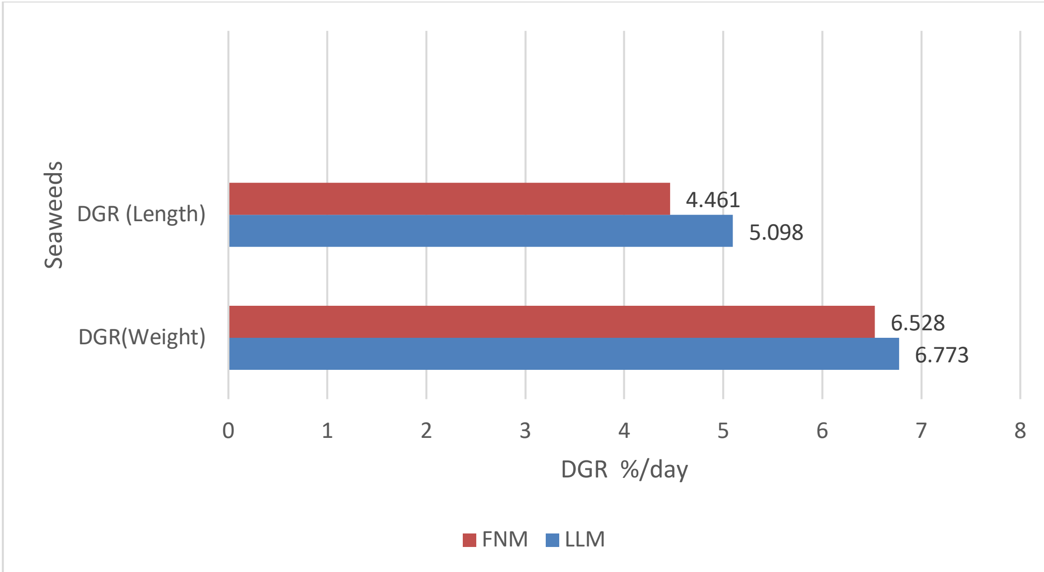


Figure 6.86 Comparison of Daily Growth Rate of Padina gymnospora in weight and length (%) per day among long line and floating net method

6.6.10 Comparison of Total Biomass of Seaweed production for LLM and FNM

For long line method, net production of biomass of was 289.328 g/m^2. Whereas, for floating net method, net production of biomass was 381.285 g/m^2. Although the value of biomass is greater in floating net method than the long line method, both methods are feasible to grow seaweed for commercial purpose.

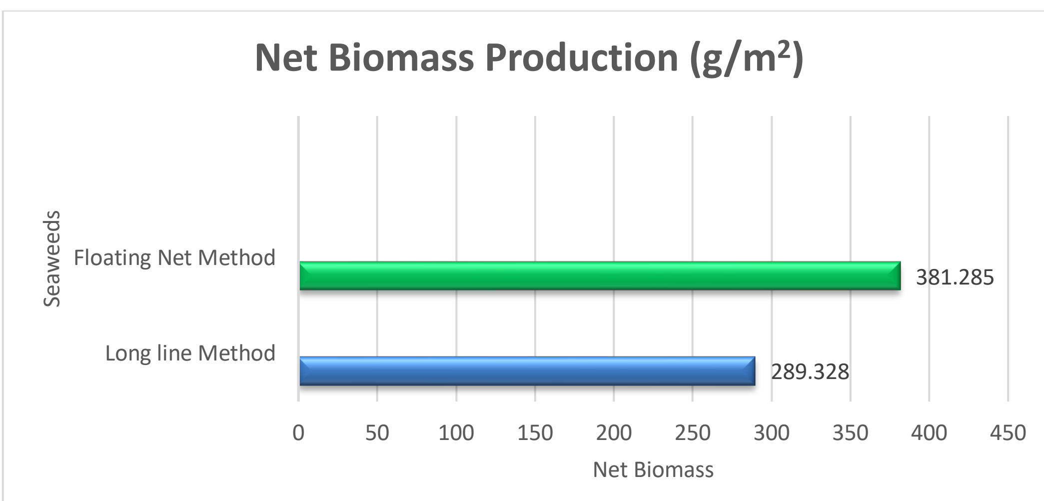


Figure 6.87 Comparison of Net Production of Biomass of Padina gymnospora among Long Line and Floating Net Method

6.6.11 Comparison of Benefit Cost Ratio (BCR) of LLM and FNM

The value of benefit cost ratio (BCR) of *Padina gymnospora* was **2.571** using Long Line Method in the coastal water adjacent to St. Martin's Island indicates that the species are economically profitable. The value of benefit cost ratio (BCR) *Padina gymnospora* was **3.272** using Floating Net Method in the coastal water adjacent to St. Martin's Island indicates that the cultivation of this species is economically profitable. Based on the results, the study concludes that floating net culture is preferable to long line cultivation for seaweed.

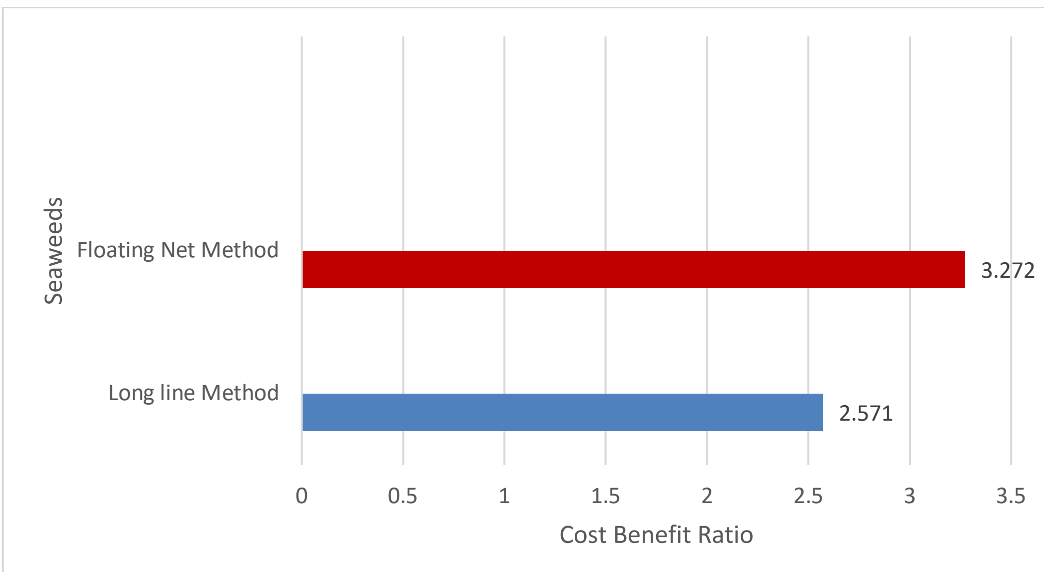


Figure 6.88 Comparison of Benefit Cost Ratio of Padina gymnospora among Long Line and Floating Net Method

Chapter 7 **Discussions and Conclusions**

7.1 Discussions

Bangladesh, possessing authority over an expansive area of around 118,813 square kilometers inside the Bay of Bengal, enjoys access to vast marine water resources that are abundant with diverse forms of life. The ocean plays a significant part in promoting socioeconomic development through generating economic activity across the nation, particularly in coastal areas. Due to its distinct topography, size, and placement within the coastal zone, St. Martin's Island, the only island in Bangladesh that contains coral, has been selected as the study area. It is without a doubt one of the most prized treasures. Additionally, this area is a suitable place for a pilot model due to its readily accessible data resources. The focus of this study is on mariculture's potential to help the island's blue economy expand. The study's goals were to identify the ideal location, time of year, and types of fish and seaweed to cultivate in the nearby island's coastal waters. The current research work studied the composition, abundance, and distribution of plankton, nutrients, heavy metals, and physiochemical properties in the coastal waters of the Bay of Bengal close to St. Martin's Island in order to achieve the study's objective. During the years 2019–2021, samples were collected at a total of twelve distinct sampling locations during different seasons of the year.

Due to the low capital needs, small-scale cage fish farming and sea weed culture gives the nation's landless poor access to an income potential. This study aims to conduct a comprehensive assessment of the feasibility of seaweed and cage culture in the coastal waters adjacent to St. Martin's Island in Bangladesh. Additionally, it seeks to investigate the impact of the marine environment, including biophysical factors, on these resources. In order to assess the seasonal variation of water quality by quantifying the physicochemical parameters study was carried out in the coastal waters adjacent to St. Martin’s Island in cool dry winter, pre-monsoon and monsoon seasons. The quality of the water is affected by agricultural practices, human habitation, unplanned infrastructure and tourism. The parameters temperature, salinity, pH, DO, EC, TDS and transparency of three seasons were measured. The average temperature from the stations ranged from 24.16ºC to 27.4ºC. Mean seasonal temperature for the pre-monsoon, monsoon and dry cool winter seasons are 26.83±0.21ºC, 27.06±0.22ºC, and 24.61±0.39ºC respectively. The salinity ranged from 24.42 ppt to 33.76 ppt, with the highest salinity (32.91±0.51) being measured in the pre-monsoon hot season. The value of pH was rather consistent throughout the year, ranging from 7.71 to 8.22, with the highest value (8.18±0.02) being measured in the pre-monsoon hot season. The amount of dissolved oxygen ranged from 4.82 to 6.74 mg/L, with the highest in the dry cool winter season (6.47±0.21 ppm) while the minimum dissolved oxygen was measured in the monsoon season (4.95±0.09 ppm). The value of electric conductivity ranged from 39.0 mS/cm to 53.46 mS/cm, with the highest value (52.06±0.90) being measured in the pre-monsoon hot season. The value of total dissolved solids ranged from 20.35 to 27.9 g/l, with the highest value (27.51±0.23) being measured in the pre-monsoon hot season. Total dissolved solids in the coastal waters was the highest in the pre-monsoon hot season while the lowest (20.98±0.35) amount was in the rainy monsoon season. The water around the island was clearer in the cool dry winter season with a range of 4.14±02 m. Furthermore, the water is least (1.45± 0.03) clear in the rainy monsoon season.

The current investigation finds congruence with prior studies examining water physico-chemistry on the Bengal coast. Specifically, a comprehensive study elucidated the mean concentrations of various physico-chemical parameters in the surface water of the region. These parameters included temperature, which was found to be 27.7±1.2 °C, pH at 7.4±0.27, electrical conductivity (EC) measured at 41.8±6.6 mS/cm, dissolved oxygen (DO) at 6.7±0.69 mg/L, and turbidity recorded at 58.5±12.0 NTU (Islam et al., 2021).

In alignment with the current research, another rigorous study conducted on the coastal waters of Parangipettai delved into the seasonal variations of physico-chemical parameters. The temperature exhibited noteworthy fluctuations across seasons, ranging from a low of 27.15°C during the monsoon season to a high of 32.4°C corresponding to the summer months. The mean temperature was calculated to be 29.53°C (± 1.23). Salinity also demonstrated significant seasonal variation, reaching a maximum of 34.33 ppt in summer and a minimum of 27.11 ppt in the monsoon season, with an average value of 31.80 (±1.83). The hydrogen ion concentration oscillated between 7.5 and 8.2, yielding a mean value of 7.97 (±0.22). As a critical determinant of water quality and aquatic life support, dissolved oxygen levels were found to range between 4.23 mgL^{-1} and 5.5 mgL^{-1}, with a mean concentration of 4.77 ± 0.34 mgL^{-1} (Vajravelu et al., 2018).

The presence of diverse phytoplankton species in the surface water surrounding the island can serve as an effective indicator for assessing factors such as productivity, water quality, marine currents, and climate modification. Abundance and distribution of phytoplankton was measured in cool dry winter season and pre-monsoon hot season in 12 different stations. After a comparative study of the abundance and distribution of phytoplankton pre-monsoon hot season was selected as the most suitable season for cage culture of herbivore fishes and further study on the diversity and abundance of phytoplankton was carried out on that season. After a detail study on the season a total of 55 phytoplankton species were recorded. The overall abundance of phytoplankton exhibited a range of 75,000-450,000 individuals per cubic meter, with the maximum abundance seen at station 10. The species *Coscinodiscus sp*. had the highest prevalence across all sampling stations, with cell densities ranging from 12,500 to 87,500 individuals per cubic meter. The collected results demonstrate that there is variation in both the composition and abundance of phytoplankton across the different sampling points. The observed phytoplankton characteristics, in terms of both quality and quantity, at the surveyed stations exhibit a notable degree of conformity with previous investigations conducted in the Bay of Bengal, namely within the geographical boundaries of Bangladesh. The species richness and diversity index exhibit similarities to those documented in other locations.

This study exhibits similarities with the findings of the following research. The Bay of Bengal coast of Bangladesh has been documented to harbor a comprehensive assemblage of 128 distinct species of phytoplankton. Among them 64 species with 23 genera of marine phytoplankton from the North-eastern Bay of Bengal was first recorded by Islam & Aziz (1975) in the early 1970's. They had also revealed 22 species of marine dinoflagellates from the Bay of Bengal by frequent studies. In the lower Meghna River estuary, Sharif et al. (2007) discovered 61 phytoplankton genera. In Sundarbans Mangrove Forests of Bangladesh, Rahaman et al. (2013) identified 134 phytoplankton species. For the first time in coastal waters around Rushikulya estuary, Baliarsingh (2015) reported 14 phytoplankton species. Among diatoms, the mostly dominated were *Consinodiscus, Chaetoceros, Thalassiosira, Pleurosigma,* and *Thalassionema*. A total of five species of dinoflagellates were identified in this study. Specifically, two species were seen from each of the genera *Ceratium* and *Protoperidinium*, while one species was found from each of the genera *Prorocentrum*, *Noctiluca*, and *Gonyaulax.*

Another study was carried out for comprehensive assessment of the zooplankton in cool dry winter season and pre-monsoon hot season in 12 different stations in the coastal water adjacent to St. Martin's Island. The assessment of the quantity and composition of zooplankton in the surface water of the research region is a pioneering endeavor, as it is the first of its kind. Pre-monsoon hot season was determined to be the most ideal season for cage culture for zooplankton feeder fish after a comparative study of zooplankton quantity and dispersion, and more research on that season's zooplankton variety and abundance was conducted.

A total of 34 distinct zooplankton species were documented across 12 sample locations. The majority of species observed in the case of zooplankton were copepods. In addition, the community also exhibited the presence of Polychaeta and Cirripedia. The species of utmost significance encompassed *Balanus, Oithona, Canthocalanus, Euterpina, and Microsetella.* The total standing crop of zooplankton exhibited a range of 55,000 to 125,000 individuals per cubic meter. Notably, station 8 displayed the largest abundance of zooplankton in terms of taxa. Upon comparing the standing crop values of phytoplankton and zooplankton obtained from the same surveyed stations, it was revealed that both the primary productivity and the trophic level of the primary consumer are relatively low. The observed species richness and diversity index of the zooplankton population appear to be similar to those reported in previous studies conducted in the Bay of Bengal. The findings of the study revealed that there is variability in both the composition and number of zooplankton among the different sampling stations. This implies that the variability is not attributable to a singular factor. There exists a hypothesis suggesting that the variability observed in this context may be attributed to a range of water quality indicators, such as water circulation temperature, dissolved oxygen levels, pH, and salinity.

This study exhibits resemblances with the subsequent studies. Sahu et al. (2010) discovered a total of 93 zooplankton species from various near shore waters within the Bay of Bengal. These species were classified into 46 different genera and 33 families, representing six distinct phyla. Within this group, copepods were observed to consist of a total of 49 distinct species, distributed throughout 21 different genera. These copepods were found to be classified into 15 families and 3 orders.

In a study by Srichandan et al. (2015), an examination was conducted on the distribution of zooplankton in the coastal region of the North-Western Bay of Bengal. The findings revealed the presence of 186 species of holoplankton and 23 distinct categories of meroplankton. The zooplankton group was primarily composed of copepods, which accounted for a total of 112 species distributed over 4 orders and 26 families. The order Calanoidae of copepods has emerged as the most dominant and widespread.

Another study also was carried to assess the nutrient and heavy metal distribution on the most prolific coral bearing island in Bangladesh during cool dry winter and pre monsoon season in 12 different stations. The island is important for its diverse ecosystem, with a diverse array of marine flora, fauna, and plankton in both marine and terrestrial systems. Moreover, the island encounters seasonal variation that directly effects the weather, bio-accumulation rate, and nutrient accumulation. Considering this, the study evaluated the concentration of nitrate (NO_3), nitrite (NO_2), silicate (SiO_4), phosphate (PO_4) and ammonium (NH_4) primarily. The study shows that in most cases, the concentrations of nutrients are higher during the cool winter season than pre-monsoon season. Nitrate, Silicates and Phosphates are the necessary component for the growth and living of sea weeds and other marine organism and ammonium and nitrite concentration is toxic after a certain range. The mean values for all nutrient concentrations were the highest during the Cool winter season (Nitrate: 0.673 ± 0.074; Nitrite: 0.139 ± 0.015; Silicate: 8.66 ± 0.253; Ammonium: 0.275 ± 0.046; and Phosphate: 0.165 ± 0.029 mg/L) and during the Pre-monsoon season the values were slightly lower (Nitrate: 0.336 ± 0.041; Nitrite: 0.102 ± 0.010; Silicate: 7.757 ± 0.389; Ammonium: 0.163 ± 0.046; and Phosphate: 0.120 ± 0.019 mg/L). During both seasons silicates and nitrate are the prime contributor of the nutrients followed by ammonium and phosphate, respectively.

The current investigation aligns substantively with prior scholarly work conducted in the Bay of Bengal, particularly a study focused on nutrient concentrations along the eastern Indian coast. This referenced study provided a granular analysis of temporal variations in nutrient levels. Specifically, nitrate concentrations were observed to peak in October 2006, registering at 24.193 µM, and minimum in December 2005 at 11.129 µM; it was also noted that lower levels were prevalent during the summer months. In contrast, phosphate concentrations reached their maximum in August 2005, measuring at 9.413 µM, and descended to their minimum in December 2005 and January 2006, at 2.232 µM. The study concluded that nutrient concentrations were most elevated during the monsoon period. Additionally, silicate levels were found to be significantly higher in comparison to both nitrate and phosphate throughout the year, with a range of 19.971 to 127.319 µM, the maximum being in August 2005 and the lowest in January 2006 (Choudhury & Pal, 2010).

The present research finds resonance with another meticulous study conducted along the central coast of the Bay of Bengal. In this study, water samples were collected from a series of coastal stations, including Gangapattinam (GAP), Krishnapattinam (KRP), Kottapattinam (KOP), Pointpudi (POP), Sriharikota (SRK), Pulicat (PUC), and Thiruvotriyur (THV). The study revealed that nitrite concentrations fluctuated between 0.32 and 1.05 µM. Notably, nitrate levels were at their zenith during the pre-monsoon season at Kottapattinam, registering at 4.82 µM, and reached their nadir during the post-monsoon season in the surface waters of Krishnapattinam, measuring at 1.07 µM. Ammonia (NH_4) concentrations exhibited a wide range, spanning from 0.10 to 42.23 µM. Inorganic phosphate concentrations oscillated between 0.24 and 2.28 µM. Furthermore, reactive silicate levels remained significantly elevated throughout the study period in comparison to other nutrients, ranging from 5.41 to 45.85 µM (Thangaradjou et al., 2014).

The samples analysis for heavy metal enumerated that the mean value of the Pre-monsoon hot season (Pb: 76.825 ± 37.91; Cu 27.478 ± 2.78; As: 0.990 ± 0.19; Cr: 3.475 ± 1.92; Cd: 6.365 ± 4.08; Zn: 44.53416667 ± 12.09 µg/L) was considerably higher in concentration than the mean value of heavy metals during the Cool winter season (Pb: 24.909 ± 9.28; Cu 23.987 ± 1.71; As: 1.0591 ± 0.31; Cr: 3.033 ± 2.23; Cd: 3.727 ± 1.26; Zn: 21.0975 ± 11.44 µg/L) in this study. The prime reason for higher concentrations of heavy metals during the Pre-monsoon hot season may be due to lower freshwater influx from upstream, a higher evaporation rate, and lower precipitation in the study area. Overall, the results indicate that heavy metal concentrations in different season are still within safe limits in the coastal water of the island.

The present study aligns closely with extant research in the field of heavy metal concentration in marine environments. For instance, a study by M.R. Hasan et al. (2016) on heavy metal distribution in the Bay of Bengal delineated the concentration of various metals in a specific order: Fe > Mn > Pb > Cu > Cd > Ni. The mean concentrations were reported as 23.68 mg/L for Fe, 1.136 mg/L for Mn, 0.452 mg/L for Pb, 0.164 mg/L for Cu, 0.012 mg/L for Cd, and 0.0066 mg/L for Ni. Furthermore, the study provided a comprehensive range for each metal, such as Fe ranging from 0.1561–60.454 mg/L and Mn from 0.52–1.80 mg/L, Pb ranged from

0.0964–0.694 mg/L, Cu from 0.119–0.192 mg/L, Cd ranging from 0.0017–0.098 mg/L and Ni ranged from 0.0055–0.1091 mg/L (M.R. Hasan et al., 2016).

In a parallel vein, research conducted by Sarker et al. (2020) on ecological risk and source apportionment in the Naf River, Shah Porir Dwip, and the coastal waters of St. Martin's Island revealed heavy metal concentrations as follows: Pb 14.7–313.0 μg L^{-1}, Cd 33.0–70.0 μg L^{-1}, Cr < 11.0–37.0 μg L^{-1}, Cu 38.0–57.0 μg L^{-1}, and Zn 26.8–69.2 μg L^{-1}.

According to the findings of the study, the pre-monsoon hot season is optimal for the highest number of phytoplankton and zooplankton, as well as other physicochemical features, nutrient concentrations, and heavy metal are suitable during that season. So, Pre-monsoon hot season was selected as the most suitable season for cage culture. On the other hand, based on the data of physicochemical properties, nutrient distribution and heavy metal and pollution indexes-Heavy metal pollution index (HPI), Heavy metal evaluation index (HEI), Nemerow Pollution Index (NPI), Total ecological risk index (TERI), Cool winter season was selected as the most suitable season for sea weed culture. But both the seasons could be considered for cage and seaweed culture as more or less all the criteria are suitable during both seasons. Based on physicochemical properties, abundance and distribution of planktons, distribution of nutrients and heavy metals area near sampling station 10, 8 and 9 was selected for cage culture of herbivore, omnivore and carnivore fish respectively. Based on the data of water parameter, nutrient concentration and heavy metal index (*HPI, HEI, NPI, TERI)* Cool winter season was selected to implant the seaweeds for cultivation as all the suitable properties needed for seaweed cultivation was found during that time but the pre-monsoon season could also be considered. Depending on physicochemical properties and distribution of nutrients and heavy metals area near sampling station 1 was selected as the most suitable station but area near station 10 and 12 could also be considered.

Mariculture is a potential avenue for economic development and food security in Bangladesh's coastal regions. However, its success will depend on careful planning, research, and collaboration with relevant authorities, experts, and stakeholders. Sustainable and responsible mariculture practices are essential to ensure the long-term viability of the industry while minimizing environmental impacts. Over the past three decades, global mariculture has witnessed a rapid escalation, with the principal contributions emanating from Asia, Europe, and South America. Despite being the world's second-largest continent, Africa's coastline spans a mere 26,000 km, attributable to the lack of deep shoreline indentations. Nevertheless, this geographical feature still affords ample opportunities for the development of coastal aquaculture. Both East and West Africa are endowed with fecund coastal ecosystems and productive estuaries, which could serve as indispensable natural resources for certain types of coastal aquaculture. However, it is imperative to note that mariculture in Africa remains in a nascent stage. As of 2009, the continent's total marine production amounted to 121,303 metric tons, constituting approximately 11% of Africa's overall aquaculture yield (FAO, 2009).

In recent years, the Government of India has undertaken a series of strategic initiatives aimed at the systematic development of the mariculture sector. There is an increasing consensus that mariculture represents a burgeoning sector, poised for transformation through technological innovation and advanced methodologies. Projections indicate that by the year 2050, India has the potential to yield approximately 4.1 million metric tons per annum of marine fish via cage culture alone, contingent upon the utilization of one percent of the nation's total coastline, which spans 8,118 kilometers. To realize this vision, the draft National Mariculture Policy advocates for the establishment of dedicated mariculture parks, to be managed by local fishing communities, cooperatives, and entrepreneurial ventures. Concurrently, it is imperative to ensure that the requisite seed (estimated at 2.46 billion) and feed (approximately 6.15 million metric tons) supplies are adequately provisioned to meet the sector's anticipated future demands (Gopalakrishnan et al., 2022).

Based on the study cage culture can be a viable aquaculture option in the coastal areas adjacent to St. Martin’s Island of Bangladesh, but its success depends on suitable season and species selection, site assessment, and adherence to environmental and regulatory considerations. Marking a milestone in Indian aquaculture, the Central Marine Fisheries Research Institute successfully deployed a marine cage for the first time in Visakhapatnam, located on the eastern coast of India, in 2007. Prior to the establishment of this pioneering cage, a rigorous evaluation was conducted to determine the suitability of the site. The primary focus of this assessment was on physicochemical parameters such as temperature, salinity, dissolved oxygen levels, ocean currents, and pollution factors, all of which are critical in ascertaining the viability of a species in a given environment (Rao, 2012). In the initial trial, a restricted quantity of Asian seabass, *Lates calcarifer*, was stocked, and a successful harvest was executed after a four-month period, coinciding with the trawl ban on the eastern coast. Subsequent economic analyses of this operation have substantiated the financial viability of cage culture within Indian maritime territories (Rao, 2009).

On the other hand, the cultivation of seaweed in the coastal areas adjacent to St. Martin's Island of Bangladesh is feasible under the suitable conditions. It can provide economic opportunities and contribute to the diversification of the aquaculture sector. The successful implementation of seaweed cultivation in the coastal regions of Bangladesh necessitates meticulous planning, extensive study, and effective collaboration with pertinent authorities and specialists.

The present research conducted in St. Martin's Island finds substantial alignment with studies undertaken in Indonesia, particularly in the realm of seaweed farming technology. This technology has undergone significant evolution and regional adaptation, with float line systems predominating the landscape. Within this system, farmers have the capability to utilize the entire water column, from surface to bottom (Najamuddin et al., 2020).

An estimated 267,000 households in Indonesia derive economic benefits from seaweed farming (Langford et al., 2021). Importantly, seaweed farming serves as a crucial income source for numerous rural households in Indonesia, often providing sufficient revenue to elevate these households above the poverty line (Rimmer et al., 2021). It should be noted that revenue streams from seaweed farming are subject to considerable variability, both inter-farm and seasonally (Mariño et al., 2019; Neish, 2013).

7.2 Conclusions

The primary aims of this study were to assess the environmental and economic viability of cage and seaweed cultivation as means of advancing the blue economy of Saint Martin's Island, Bangladesh. Based on the findings of all the research on the physicochemical properties of the water, abundance and distribution of phytoplankton, zooplankton, nutrients and heavy metals feasibility of commercially important seaweed and cage culture in the Saint Martin's Island, Bangladesh was explored. The result of the measured parameters indicated that the water adjacent to St. Martin's Island is optimum for seaweed and cage culture. After analyzing the physical properties of water, plankton, nutrients and heavy metal, it was clearly seen that St. Martin's island is environmentally and economically feasible for cage culture. The culture of the fish was conducted from January, 2022 to May, 2022.

Depending on availability of plankton and supplementary feed and suitability of physicochemical properties of seawater, nutrients, heavy metals and other important criteria- the Milk fish (*Chanos Chanos*), a herbivore fish, the John's Snapper/John's Sea Perch

(*Lutjanus johnii*) and Asian Sea Bass (*Lates calcarifer*), both carnivorous species, and the Flathead Grey Mullet (*Mugil cephalus*), an omnivore fish was selected for cultivation in the coastal waters adjacent to the island. John's Snapper (*Lutjanus johnii)* was taken as the representative species to evaluate the economic viability of cage farming in this study. After being raised in cages in the coastal waters near St. Martin's Island, the Benefit-Cost Ratio (BCR) values for *Lutjanus johnii* (John's Snapper), was **1.1651**. From BCR, it was clearly seen that cultivating John's snapper in cage at St. Martin's island is economically feasible. The study suggested that as *Chanos chanos* is an herbivorous fish and it doesn't require additional food. So, it may be considerably simpler for local unemployed people to raise this fish than other species. It will be difficult for the poor and jobless without any economical support from Government or NGOs to raise *Lutjanus j*ohnii, *Lates calcarifer* and *Mugil cephalus* because they require supplementary diet. However, large-scale commercial cage culture of those species has the potential to yield extremely significant profits. Additionally, several of the issues and limitations related to fish farming in cages were revealed by this study.

The study also confirmed that, from an ecological, environmental and economic standpoint, the studied area has a very high possibility of seaweed culture. Moreover, it is investing heavily in the long-term growth of the blue economy from a global oceanic perspective. This study found a sizable number of edible seaweeds that can be grown in this location for commercial purposes. The seaweed cultivation feasibility studies on this island indicate a favourable outcome, which will contribute to the sector's future growth. Given the results of the research on physicochemical properties, nutrients concentration and distribution and heavy metal and pollution indexes suitable site, season and species of seaweed was selected. Based on the study, area near Station 1 was selected for seaweed cultivation. It was possible to cultivate seaweed throughout both the cool dry winter season as well as the pre-monsoon hot season; however, the cool winter season was more favorable. On the basis of all the investigations*, Ulva intestinalis (Green algae), Gracilaria gracilis (Red algae), and Padina gymnospora (Brown algae)* were chosen as the edible and commercially significant species for cultivation as salinity, temperature, transparency, pH, DO, nutrients, heavy metals, and other characteristics of the water were ideal for the cultivation of those species. The nutritional content of St. Martin's Island's water and other parameters indicated that seaweed cultivation was highly viable in the island's coastal waters. Due to the availability of seedlings, *Padina gymnospora* was chosen as the representative species to assess the economic viability of cage farming in this study.

The fact that the value of benefit cost ratio (BCR) for *Padina gymnospora,* using the Long Line Method in the coastal waters adjacent to St. Martin's Island was **2.571** indicates that this species is economically profitable. The value of cost benefit ratio (BCR) for *Padina gymnospora* was **3.272** when using the Floating Net Method in the coastal waters adjacent to St. Martin's Island indicates that the cultivation of the species can result in a positive financial outcome. The study comes to the conclusion that floating net culture is superior to long line cultivation for the purpose of growing seaweed based on the data. The obtained results indicated that the limitations of seaweed cultivation can be easily controlled. Some anthropogenic causes, such as urbanization of this natural island and tourism, may have a negative impact on this culture, but proper awareness and raising activities can be beneficial.

In conclusion it could be said that cage and seaweed culture in the coastal area adjacent to the island and as well as the other coastal areas of the country could be very much profitable. If fishermen, farmers, local unemployed people even local women get access to cutting-edge inputs and production technology and economical support in a timely manner, yield and production of fish and seaweed may rise which can boost their income and living conditions. It may aid in enhancing nutritional status of poor inhabitants of the island. The results, however, made it abundantly evident that there is plenty of room to increase the annual yield of fish production by cage culture and seaweed production by seaweed culture in the coastal area which can play a very important role to promote blue economy of both the island and the entire country.

Chapter 8 **Recommendations and Limitations**

8.1 Recommendations

In order to optimize the productivity, efficiency, and efficacy of fish and seaweed farming, the subsequent recommendations are proposed:

i. Seaweed and cage culture could be an alternative source of income for the unemployed people of the Island. Involvement of women in this culture can be a big opportunity for women empowerment. This will also contribute to an equitable distribution of benefits for both men and women.

ii. Seaweed and cage culture in a scientific way will never harm the ecological environment. On the other hand, seaweed and cultured fish in cage could be source of nutrients and vitamins, so commercial and edible seaweed culture and cage culture could be alternative source of nutrients for local people as well as the whole country.

iii. Government should provide initial funds for cage construction and seaweed site installation and other inputs needed for cage and seaweed culture, fair prices for inputs/raw materials should be guaranteed so that farmers can purchase them at a cost they can afford.

iv. Research on other coastal area should be done to find out the suitable site, season and species for cage and seaweed culture in that specific area.

v. Investigation should be done to determine the true reasons of diseases caused by bacteria, viruses, and other pathogens. Regular monitoring and proactive disease management strategies can help prevent disease outbreaks in the cage and seaweed culture zone area.

vi. Interested unemployed people or women should have access to bank loans and institutional credit on simple terms that they can start cage and seaweed culture as it is practiced in Tamil Nadu, India and Taiwan.

vii. Scientific cultivation techniques should be used to boost output. Farmers should be given the appropriate infrastructure, training, knowledge, and services to deal with new and changing circumstances.

viii. The research area's marketing and transportation infrastructure should be improved specially there should be an easy channel of selling produced fish and seaweeds.

ix. To mitigate social tension and improve conditions in fish farming regions, it is imperative for law enforcement agencies to exercise vigilance within the research domain.

x. To increase awareness among the unemployed, flyer distribution, billboard placement, posture, and seminars about cage culture and commercially significant seaweed culture in the coastal area could be carried out.

xi. Community-based conversation program involving different ages and occupations can boost up this commercially important seaweed and cage culture.

xii. Finally, the government should establish a regulatory framework to govern mariculture activities in future in Bangladesh. This framework should address issues such as licensing, environmental impact assessments, and enforcement.

By implementing these recommendations, Bangladesh can develop a sustainable and profitable mariculture industry that can contribute to food security, employment generation, and economic growth. As a pilot experiment, the investigation was carried out in the coastal waters close to St. Martin's Island. To get the bigger scenario of the whole coastal area of the country further study that includes different Bay of Bengal geographic regions may be done which could play a very important role in the long run for promoting blue economy of the country.

8.2 Limitations of Mariculture Study

1. Inadequate knowledge and data on seaweed and cage culture in coastal region.
2. Secondary data were contradictory and extremely challenging to collect.
3. Despite advances in mariculture technology, our knowledge of the biology of many marine species remains limited. This lack of knowledge can make it difficult to develop efficient and effective techniques for the mariculture of certain species.
4. Mariculture research requires significant investment in infrastructure, equipment, and personnel. This can be a barrier for smaller research organizations or developing nations.
5. The sensitivity of marine organisms to environmental factors such as temperature, salinity, pH, and water quality is well-established. Changes in these factors can affect the growth and health of the cultured organisms, making it difficult to conduct consistent research.
6. Mariculture is governed by a variety of regulatory frameworks, which can vary between countries and regions. These regulations can restrict where and how mariculture can be conducted, thereby limiting the scope of possible research.
7. A variety of diseases and parasites can inhibit the growth and productivity of marine organisms. In addition to affecting research, disease outbreaks can reduce the number of healthy organisms available for study.
8. Mariculture can sometimes face opposition from local communities or environmental groups. This can pose challenges for research, particularly if it is conducted in areas where mariculture is not widely accepted.

Overall, mariculture research has the potential to significantly contribute to food security and economic growth; however, these limitations must be carefully considered and addressed to ensure the success of research efforts.

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